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Assessing the Functional Status of Created Wetlands in Eastern Virginia Via a Soil and Vegetative Developmental Trajectory

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ABSTRACT PAGE

Creation of wetlands has been used since the 1980s as a tool for the mitigation of natural wetlands lost to development. Although current wetland policy attempts to compensate for lost wetland acreage, replacement of function may lag considerably. To measure this suspected lag, I evaluated the plant community and soil composition of nine created palustrine forested wetlands in Virginia relative to natural reference wetlands. A previous study (Fajardo 2006) indicated that the vegetation and soil composition was far from that observed in natural wetlands. This study re-sampled these wetlands in 2008 to determine whether the functional gap between created and natural wetlands has changed with age, and to create a baseline for future assessment. Plant communities were analyzed for the presence of hydrophytic vegetation (weighted average) and species richness. Our results showed that all sites had >50% plots dominated by hydrophytic vegetation and most exhibited positive successional changes represented by more woody species. Soil cores were obtained from around the vegetative plots and analyzed for physical, chemical, and morphological properties. Organic matter nearly doubled (to 4.41%). C increased, while N, Fe, and P increased significantly (to 1.68%, 0.17%, 0.75%, 159 mg/kg respectively), while C:N decreased significantly (to <14:1). Modified Soil Particle Density decreased significantly in most sites. Three sites exhibited soil chroma changes towards becoming more oxidized, four more reduced, and two saw no overall change. Results of this study could be used to validate the untested assumption that created palustrine forested wetlands may attain the functional equivalency of wetlands lost to development.

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Chapter 1. Introduction and Literature Review

1.1 *INTRODUCTION*

Since the policy of "no net loss" was adopted by former President George H. Bush in 1989, compensatory mitigation has become a widespread practice throughout the United States. The short-term goal of "no net loss" is to halt the decline in the overall wetland area of the U.S., while the long-term is a net gain of the country's wetlands (Sibbing n.d.). "No-net-loss" calls for the mitigation of impacts to wetlands, and calls for creation or restoration of wetland sites damaged due to unavoidable impacts to natural sites through in-kind replacement when possible (Salzman and Ruhl 2006).

Developers who cannot avoid construction to wetlands must acquire a special permit in order to proceed, which also requires a mitigation plan in order to replace the impacted wetland type. This is achieved through negotiations with the Department of Environmental Quality (DEQ). The plan options include preservation, restoration, and creation of wetlands. However, only restoration and creation calls for an end result of an overall increase in wetland area relative to the area impacted. Restoring wetlands involves transforming natural sites that have been degraded by anthropogenic forces, usually by land conversion from hydrologic diversion, by reestablishing the hydrology and vegetation that once dominated the landscape. Preserving wetlands requires purchase and donation of a large natural site (or multiple sites) in order to prevent future developers from impacting those sites. Creating wetlands usually involves the conversion of upland environments to wetland environments by removing soil horizons from the landscape until the appropriate depth is reached, usually close to the seasonal high water mark. As a result, groundwater and/or surface runoff are able to affect the landscape in ways that strongly influences the development of soil and vegetation.

The "no-net-loss" wetlands' policy is excellent in concept in that it proposes to eliminate further total wetland losses in the United States, a country that has already lost more than 50% of wetland resources in just its first two-hundred years (Dahl 1990; Ohio Division of Wildlife). However, studies have shown that "no-net-loss" did not become the planned success it was originally anticipated to be (Zedler and Callaway 1999; Sibbing n.d.; Salzman and Ruhl 2006). Permits usually require a monitoring time of five to ten years. However, many permits are not followed through on, and many sites are never created. This is usually due to limited oversight and enforcement by the ACOE (Salzman and Ruhl 2006).

Additionally, due to limited knowledge of developers and researchers and natural fluctuations, sites may develop into a wetland type different from that required by the permit (i.e., emergent growth rather than forested) (Cole and Shafer 2002). Permit holders often monitor sites for only a short period of time, and they may erroneously expect that the sites are nearing functional wetland status. In mitigation of climax communities (i.e., forested wetlands), the literature shows that five to ten years may be too short of a time for the sites to mature and fully compensate for those wetland areas and their functional losses (Zedler and Callaway 1999; Giese and Flannagan, unpublished data).

In order to account for low success rates in replacement capabilities, the U.S. Army Corps of Engineers (ACOE) mandated that developers create additional area beyond the size of what was originally impacted. These mitigation ratios are based on the relative success of compensation (i.e., creation and restoration) efforts to date. Emergent wetlands are relatively easy to replace qualitatively, followed by shrub-scrub, and then forested wetland types. The required mitigation ratios (required acres: impacted acres) are 1:1, 1.5:1, 2:1, respectively (VDEQ n.d.); although some studies recommend that even these figured may not be sufficient (Robb 2002). Sites that are particularly unique may require $\geq$ 5:1 acres to be mitigated in compensation (MDEQ n.d.).

The nationwide success of restored and created wetlands is limited as a result of insufficient remediation efforts of permit holders (Kettlewell et al 2008; Maguire 1985; Race 1985; Mager 1990; Holland and Kentula 1992; Zedler and Callaway 1999; Cole and Brooks 2000; Robb 2002; Kihslinger 2008). Many permit holders comply with the minimum requirements of planting and then move on without any monitoring (Salzman and Ruhl 2006), while others avoid compensation by not creating or restoring sites at all (Robb 2002).

Most often, the success of mitigation is based on the existence of a completed mitigation project, rather than success of individual sites in replacing wetland functions. The need for compensation policy is still essential. New policy that legislates more effective sites, larger mitigation ratios (Zedler and Callaway 1999), and consistency in construction methods may needed to insure improvement in the functional statuses of created sites.

Based on the goals of governmental policy, there is a need to design successful created forested wetland sites. There exists a lag in wetland creation science in that created forested sites take longer to mature than the science has existed. Few studies have incorporated a *temporal* component to evaluate functional status while establishing a *baseline* for future studies (O'Donnell and Galat 2008).

The theory of a set developmental trajectory, the supposedly clear pathway that created sites follow in order to meet some hypothetical quantitative and qualitative goal of functional success, may only be viable as just that, a theory (Zedler et al. 2001). However, providing the necessary hydrologic, soil, and vegetative background, and sufficient time for development might foster a created wetland's functional improvement. Nevertheless, some aspects of the design must be left to natural development (Mitsch and Gosselink 2000).

Current policy is based around the central concept of monitoring created sites for up to the first decade. Jørgenson (1994) reported that the further initial conditions are from their natural state, the longer it takes for that system to reach equilibrium within the natural system. As a result, it may take many centuries to reach a stable equilibrium with nature. While a true final age of maturity for these sites may never be fully agreed upon, a more appropriate length of monitoring may be invaluable for adjusting policy requirements for mitigation.

A realistic trajectory might allow developers to more accurately envision the changes that may occur at sites over time, in order to better evaluate the different methods of creating wetlands that yield the more effective functional outcome. As required by the permitting authority, hydrology, soils and vegetation are monitored for up to ten years by the creator. However, after this time, many permit-holders assume that the sites are equivalent with reference sites and will continue to be. In many instances, sites are minimally monitored after this marker (Salzman and Ruhl 2006), or this information is not disseminated to show that monitoring has occurred and to share the results of the research (O'Doonnell and Galat 2008). Monitoring may characterize trends rather than assess project effectiveness (O'Doonnell and Galat 2008), and/or created sites do not resemble or function as natural wetlands at project completion (Race 1985; Reinartz and Warne 1993; Mitsch and Wilson 1996; Cole and Brooks 2000).

This study shows that consistent and increased monitoring may be necessary in order to ensure correct developmental growth, and that proven methods of site creation must become standard. In order to determine some of the most effective wetland creation methods, I am creating a baseline of key wetland characteristics at nine created palustrine forested wetlands.

The specific aims of this study were to:

1. Determine the relative effectiveness of wetland construction practices over time, such as application of organic amendments, or the use of cut versus filled sites; and

2. Evaluate the change in vegetative cover, species dominance, and successional change (i.e. presence of woody species) over time in created wetlands, in order to determine if the sites exhibit characteristics consistent with natural wetland indicators; and

3. Analyze the change over time of key soil characteristics and determine if the created sites exhibit characteristics consistent with natural wetland indicators; and

4. Illustrate a developmental trajectory of potential growth in created wetlands according to actual development, as compared to reference sites, in order to visually evaluate any changes over time towards becoming functional, mature sites.

1.2 *FUNCTIONS AND VALUES OF WETLAND ECOSYSTEMS*

Wetlands exist as ecotones in the environment, functioning as the transition between aquatic and terrestrial environments (Cowardin et al. 1979, Mitsch and Gosselink 2000; Dahl 2006) because they share characteristics of both distinct systems. Wetlands are terrestrial systems with anaerobic soils for at least part of the growing season, while the dominance of trees, shrubs, grasses, mosses and other vascular plants distinguishes wetlands from aquatic systems (van der Valk 2006). Specifically, the boundary between the wetlands and aquatic environment lies at rooted emergent vegetation.

Natural wetland functions include trapping excess nutrients, nutrient cycling (Giese and Flannagan, unpublished data), and serving as habitat for unique biota and environments for sediment to settle out of the water column. Values for humans that go beyond the health of the single ecosystem are numerous and varied. Wetlands mitigate flood events (EPA, 1995), aid as aquifer recharge mechanisms (Salzman and Ruhl 2006; Mitsch and Gosselink 2000), and serve as nurseries for fish and shellfish in coastal areas and habitat for plant and vertebrate populations (Dahl 1990; Mitsch and Gosselink 2000; Salzman and Ruhl 2006). Additionally, wetlands function to clean wastewater by settling excessive sediment and filtering toxic pollutants (Mitsch and Gosselink 2000).

There is an undeniable need for wetlands in the global economy and society. The question is how to convey this need to people outside of the field who might otherwise be interested in preserving this resource. This anthropocentric view of wetlands implies that they hold certain values: something of worth, are useful, or otherwise provide something advantageous for humans that arises from natural wetland functions (Brinson and

Rheinhardt 1998; Mitsch and Gosselink 2000). All wetland sites provide natural functions, some more than others; however, not all of these functions may be documented or viewed as providing societal values.

1.3 *HISTORY, POLICY, AND REGULATION*

As a result of negative sentiments and poor government policies, more than 50% of American wetlands were depleted in the country's first 200 years (Mitsch and Gosselink 2000; Ohio Division of Wildlife n.d.; Dahl 1990). Sites were drained or filled to be used for agricultural, forestry, and coastal land development (Mitsch and Gosselink 2000; Dahl 2006). Dahl (1990) estimated that while some states had lost very few wetlands, others had lost nearly 90% by the 1980s. By this point, Virginia had lost 42% of its wetlands (Dahl 1990).

Changing public attitudes toward industrial impacts on the environment led to legislation in the 1970s which brought protection for wetlands with section 404 of the Clean Water Act (1977) (Mitsch and Gosselink 2000). In this legislation, wetlands are protected to help maintain the health of U.S. waterways. Through this act, the U.S. Army Corps of Engineers (ACOE) was given the authority to grant or withold permits to developers to dredge or fill wetland environments, and in essence became a "Protector" of water resources (ACOE 2004) The ACOE defined these sites as:

> Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (Environmental Laboratory 1987).

The ACOE solicited the advice of the U.S. Fish and Wildlife service (FWS), as well as the U.S. Environmental Protection Agency (EPA) and other government departments in order to design the standards for wetland protection and mitigation.

The ACOE Regulatory Program protects wetlands by encouraging developers to circumvent losses and mitigate those that are unavoidable (ACOE 2004; US EPA 2004). Sites with especially rare habitats or species are usually better protected through the developer's need to mitigate impacts to these sites with higher ratios (Granger 2004). Although 97% of permit applications are granted (Totenberg 2006), the lengthy and expensive process has helped to deter development in these environments and the rate of wetland loss has decreased since the 1950s (Bridgham et al. 2006; Dahl 2006).

To further mitigate local impacts from converted wetland sites, the EPA and the ACOE favor compensation efforts that produce on-site and in-kind developments (Salzman and Ruhl 2006). An on-site versus an off-site development refers to creating a wetland < 1km from the impacted site. An in-kind wetland attempts to recreate the wetland that was lost, according to its Cowardin classification (Cowardin et al. 1979). In this way, the watershed has the potential to regain the functions lost to the developed site.

Compliance can be achieved by a variety of methods including restoration of areas that were historically wetland areas, enhancement of low-quality, damaged wetlands (both methods of restoration), or creation of a wetland in a historically upland or deepwater area, and the preservation of existing wetlands (Mitsch and Gosselink 2000; Norfolk District Corps and VDEQ 2004; Salzman and Ruhl 2006; Virginia State Water Control Board 2007). As mentioned earlier, the method of compliance is up to the developer and the Department of Environmental Quality (DEQ); however, options of restoration and creation are favored by the Virginia State Water Control Board (2007) since this increases total local wetland area. However, it also makes compensation with immature wetlands more financially favorable than maintenance of mature sites (Salzman and Ruhl 2006). Achieving functional success at created sites is a long process with mixed results (Kettlewell et al 2008; Eliot 1985; Race 1985; Mager 1990; Holland and Kentula 1992; Maguire 1985 and Reimold and Cobler 1985 from Mitsch and Wilson 1996; Zedler and Callaway 1999; Streever 1999; Cole and Brooks 2000; Robb 2002; Dahl 2006).

The national policy of "no-net-loss" was first devised by the National Wetlands Policy Forum (The Conservation Foundation 1988), and later adopted into national policy by George H.W. Bush in 1988 (Dahl 2006). A study twelve years later by the National Research Council (2001) showed that despite efforts, around 60,000 acres were still lost in the United States annually (NRC 2001; Esty 2007). In 2004, George W. Bush set an ambitious goal to improve and protect more than three million acres of wetlands within a five year period (Dahl 2006).

In a follow-up report by Kihslinger (2008) only a fraction of the sites that had been implemented according to permit requirements were deemed functionally successful. This loss represents the failures of both implementation and functional failure of both individual and banking mitigation sites (Mack and Micacchion 2006; Kettlewell et al 2008 Kihslinger 2008), that have resulted from the issuance of around 80,000 permits per year (Stokstad 2008) to mitigate 47,000 acres of wetland per year (Kihslinger 2008). The Government Accountability Office faulted the ACOE for this discrepancy, as a result of their not asserting jurisdiction in monitoring the outcomes of wetland permitting.

In recent years, the Clean Water Act has also fallen under scrutiny which has affected the protection of natural wetlands. In 2009, the Clean Water Restoration Act was established with the hope to define the CWA for wetlands all waters (Clean Water Action). Regardless, wetlands in Virginia were protected during this time because state laws are more stringent than Federal (e.g., Virginia Constitution - Article XI, Section 1, 1972 VA Wetlands Act, and Virginia's Chesapeake Bay Preservation Act). Additionally the Norfolk District Corps and VDEQ (2004) lay out rigorous guidelines for constructing wetlands.

1.4 *WETLAND CRITERIA*

A jurisdictional wetland is one that is legally considered to be a wetland under Section 404 of the Clean water Act (ACOE 2008). These sites must be defined by effective wetland hydrology, hydrophytic vegetation, and hydric soils (Mitsch and Gosselink 2000; Whittecar and Daniels 1999). Moreover, these characteristics are not independent.

1.4.1 Wetland Hydrology Criteria and Indicators

Effective wetland hydrology may by characterized by the frequency and duration by which the depth of the water table saturates or inundates the upper soil substrate during at least part of the growing season, in order to support hydrophytic vegetation (Mitsch and Gosselink 2000; ACOE 2008). Wetland indicators provide evidence of a continuing hydrologic regime, rather than a historical one (ACOE 2008).

Being transitional environments, there also exists a gradual topographic cline at sites between upland and the wetland environments. According to site morphology, wetlands may be fed by any combination of groundwater infiltration, precipitation, and/or stream overflow (Mitsch and Gosselink 2000). Before developing land into a created wetland, the hydrology should be monitored via piezometers (i.e., wells) for a few growing seasons to determine the overall hydroperiod that the site might experience during any given year (Whittecar and Daniels 1999; Mitsch and Gosselink 2000). The ACOE requires that:

> The site is inundated (flooded or ponded) or the water table is ≤12 inches below the soil surface for ≥14 consecutive days during the growing season at a minimum frequency of 5 years in 10 (≥50% probability). Any combination of inundation or shallow water table is acceptable in meeting the 14-day minimum requirement. Short-term monitoring data may be used to address the frequency requirement if the normality of rainfall occurring prior to and during the monitoring period each year is considered (ACOE 2005).

Indicators of wetland hydrology in the Atlantic Coastal Plain Region (ACOE 2008):
In order to determine if wetland hydrology is present, the site must exhibit either one primary indicator, or two secondary indicators.

1. Direct observation of surface water or groundwater.
    a. Primary: Surface water, high water table, saturation.
2. Evidence that a site is subject to flooding or ponding.
    a. Primary: water marks, drift deposits, sediment deposits, algal mat or crust, Fe deposits, inundation visible on aerial imagery, water-stained leaves, aquatic fauna.
    b. Secondary: surface soil cracks, sparsely vegetated concave surface, drainage patterns, moss trim lines.
3. Other evidence that the soil is, or was recently saturated.
    a. Primary: H_2S odor, oxidized rhizospheres along living roots, presence of reduced Fe or S in the soil profile, recent Fe reduction in tilled soils, thin much surface.
    b. Secondary: dry-season water table, crayfish burrows, saturation visible on aerial imagery.
4. Landscape vegetation and soil features indicative of contemporary wet conditions.
    a. Secondary: geomorphic position, shallow aquitard, FAC-neutral test.

1.4.2 Hydric Soils Criteria and Indicators

Hydric soils are "soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register 1994). Saturation or inundation depletes the soil of new oxygen inputs since the gas diffuses 10,000 times more slowly in water than in air

(Greenwood 1961; Brady and Weil 2008). The soil oxygen is quickly utilized by the flora and microbial biomass for metabolism until it is depleted, at which point the microbial biomass becomes dominated by anaerobes that utilize alternative elements as terminal electron acceptors (TEA) when breaking down the organic matter (Mitsch and Gosselink 2000; Brady and Weil 2008). There exists a hierarchical schematic for the metabolism of soil organic matter according to the redox potentials at which they were observed to occur (Table 1) (Mitsch and Gosselink 2000; Bailey et al. 2007; Brady and Weil 2008). When oxygen is depleted, the soil redox potential falls below 0.38 to 0.32 V, and the next most easily reduced substance, nitrate, is reduced, etc. (Brady and Weil 2008). The result is anaerobic soils.

Soil colors change as a result of oxidation or reduction of certain elements which results in the transformation, accumulation, or loss of these compounds from the soil solution (Table 1). The compounds are the basis for a range of *redoximorphic features* which vary in color, and as a result, comprise a large portion of hydric soil field indicators (Megonigal 1993; Fajardo 2006; Brady and Weil 2008; USDA NRCS 2010). The reduction of elemental oxides like iron and manganese remove the colors from the soil particle surfaces which results in the predominance of a gray soil matrix (*reduced matrix*), and similarly- *redox depletions* (Mitsch and Gosselink 2000; Brady and Weil 2008; USDA NRCS 2010). These elements can be re-oxidized as *redox concentrations* elsewhere –most notably in the rhizosphere where hydrophytic plant roots have the potential to leak excess oxygen – as pore linings, root channels, or iron oxide plaques (Mitsch and Gosselink 2000; Weiss et al. 2003; Neubauer et al. 2007; Brady and Weil

2008). The presence of these and certain other indicators are considered proof-positive field evidence of hydric soils (Fajardo 2006).

Table 1: Oxidized to Reduced Forms and Charge for Several Elements and Redox Potentials E_h at which The Redox Reactions (Oxidation-Reduction Reaction) Occur in a Soil at pH 6.5 (Adapted from Brady and Weil 2008: Table 7.1).

Element	*Oxidized form*	*Charge on oxidized element*	*Reduced form*	*Charge on reduced element*	*E_h at which change of form occurs, V*
Oxygen	O_2	0	H_2O	-2	0.38 to 0.32
Nitrogen	NO_3^-	+5	N_2	0	0.28 to 0.22
Manganese	Mn^{4+}	+4	Mn^{+2}	+2	0.22 to 0.18
Iron	Fe^{3+}	+3	Fe^{2+}	+2	0.11 to 0.08
Sulfur	SO_4^{2-}	+6	H_2S	-2	-0.14 to -0.17
Carbon	CO_2	+4	CH_4	-4	-0.20 to -0.28

Since anaerobic metabolism occurs much more slowly than aerobic transformations (accumulation exceeds the rate of decomposition), hydric soils can usually be characterized by high levels of organic matter (Whittecar and Daniels 1999; Mitsch and Gosselink 2000; Norfolk District Corps and VDEQ 2004; Brady and Weil 2008). This is especially true in the surface layers where litter is deposited directly by hydrophytic vegetation. The rate of decomposition by the microbial biomass is regulated by environmental conditions including, but not limited to temperature, pH, litter palatability and supply of TEAs (Mitsch and Gosselink 2000), and site hydroperiod (Stolt et al. 2001).

Hydric soil indicators in the contiguous United States (USDA NRCS 2010):

All soils have a dominant chroma of ≤ 2, or if >2, unless noted (*), the thickness of the layer(s) is < 15cm. Nodules and concretions are not considered to be redox concentrations, unless noted (^).

1. Soil indicators for all soils (any USDA texture):
    a. All Histosols except Folists, Histic Epipedons, Black Histics
    b. Hydrogen sulfide
    c. Stratified layers, depleted below dark surface, thick dark surface
    d. Organic bodies, muck presence, coast prairie redox*
2. Sandy soil (texture of loamy fine sand and coarser) indicators:

a. Sandy mucky mineral, mucky peat or peat, sandy gleyed matrix, sandy redox, stripped matrix*,
b. Dark surface, thin dark surface, poly value below surface
3. Loamy and clayey soil (textures of loamy very fine sand and finer) indicators:
a. Loamy mucky mineral,
b. Loamy gleyed matrix, depleted matrix
c. Depleted below dark surface, thick dark surface, redox dark surface, depleted dark surface
d. Redox depressions*, vernal pools, marl,
e. Depleted ochric, umbric surface,
f. Iron-manganese masses*
g. High plains depressions^, delta ochric, reduced vertic
h. Piedmont flood plain soils*
i. Anomalous bright loamy soils*

1.4.2.1 Physical Soil Properties

1.4.2.1.1 Modified Soil Particle Density (MSPD)

Modified soil particle density (MSPD) is a measure of the mass of dry soil within a certain volume, typically measured in grams per cubic centimeter. Typical mineral soils have MSPDs around1.25 g/cc, but these values can increase to 2.00 g/cc and occasionally even higher in more compact soils. Compacted soils occur as a result of construction from heavy machinery which has the potential to create layers such as traffic pans under the right moisture regime (Brady and Weil 2008). This compaction cannot be reversed naturally for decades or centuries, so instead, deep ripping of the soil may be necessary. Soils become root limiting to vegetation between 1.45 g/cc for fine textures to 1.75 g/cc for coarse loamy textures (Daniels and Whittecar 2004).

As a result of this compaction, soil particles are pushed closer together which may reduce infiltration capacity, and soil pore space. Since soil pores hold both gases and water, a decreased volume of pore space reduces the water holding capacity of the soil, and MSPD is therefore increased (Fajardo 2006; Brady and Weil 2008).

Correspondingly, soil strength then increases (Brady and Weil 2008) which can severely retard or fully prevent vegetative rooting ability, through its inability to push through the soils (Nair et al. 2001; Fajardo 2006).

Surface soils are more likely to contain higher levels of organic matter, which has a lower particle density. Surface soils also tend to be characterized by more soil aggregation and higher concentrations of roots and soil-dwelling organisms that also breakdown the soil. These are all factors that lead to lower MSPDS (Brady and Weil 2008). Deeper horizons are normally affected by contrary characteristics, and can also become compacted from the addition of the weight from upper horizons, which results in higher MSPDs (Brady and Weil 2008).

1.4.2.1.2 Organic Matter

Soil organic matter (OM) is comprised of the remains of biota including the living soil microbial biomass, as well as the stable organic humus (Brady and Weil 2008). It supports macroinvertebrates, increases the cation exchange capacity (CEC), hydraulic conductivity, and water holding capacity of the soil, reduces modified soil particle density and increases aggregation, removes toxins and metals from the soil solution, releases nutrients for floral and faunal uptake, and stores global C (Mitsch and Gosselink 2000; Bruland and Richardson 2004; Bailey et al. 2007; Brady and Weil 2008). Since OM exerts so much influence over these important characteristics it is frequently utilized as a measurement to assess hydric soil development, and overall functional status (Nair et al. 2001; Fajardo 2006).

Organic matter can be oxidized quickly in aerobic systems (i.e. upland environments), especially in warm, dry climates, where decomposition rates are greater than rates of accumulation (Brady and Weil 2008). In anaerobic wetlands, decomposition is hindered which allows OM to accumulate much more readily (Mitsch and Gosselink 2000; Brady and Weil 2008). This accumulation occurs most readily at the surface layers, which exhibit typical characteristics of containing high levels of OM: lower mass, lower modified soil particle density, higher moisture content, and higher porosity (Bailey et al. 2007). Correspondingly, the deeper soil layers which typically contain less OM, are characterized by: higher mass, lower porosity, lower moisture content, and much higher MSPDs.

A soil OM level of 4% is deemed the standard target for mineral organic wetland soils since that is the reference natural forested wetland average (Atkinson et al. 1993; Cummings 1999). Soil OM levels may take decades to reach the equivalent depths of reference natural wetlands (Odum 1969; Windham et al. 2004; Bailey et al. 2007). In order to jumpstart growth at the systems, many studies recommend using OM amendments in creation methods and guidelines (Bischel-Machung et al. 1996; Brinson and Rheinhardt 1996; Mitsch and Gosselink 2000; Cole and Brooks 2000; Stolt et al. 2000; McKinstry and Anderson 2003; Daniels et al. 2005; Norfolk District Corps and VDEQ 2004; Bailey et al. 2007; Bruland et al. 2009). Additionally, Bailey et al. (2007) recommended a rate of application of 112 Mg/ha as the optimal amendment to increase nutrient levels and overall primary production levels to those consistent with natural systems, while minimizing elevation changes. Topsoil from the disturbed natural site may serve as an additional organic source when stored properly. This soil is usually laden with a natural seedbank and microbial biomass, and has been shown to create more desirable soil conditions in created sites (i.e., lower bulk density, higher water holding capacity, etc.) (Bruland and Richardson 2004).

1.4.2.1.3 Chroma

The chroma of a soil indicates the purity, strength, or saturation of the color (Munsell Soil Color Charts 2000; Brady and Weil 2008). Darker chroma (lower numbers) indicate higher levels of organic matter coating the particles in the soil layer. Megonigal et al. (1993) found chroma to be strongly correlated with redox potential and soil O_2 content, and found gleying and low chroma to be a proxy measurement for more detailed measurements of redox potential (Brady and Weil 2008). More specifically, soil chroma ≤ 2 indicate periods of anaerobic conditions (Hossler and Mitsch 2004; USDA NRCS 2010).

1.4.2.2 Soil Chemical Properties

1.4.2.2.1 Total Nitrogen

Nitrogen is the first element after oxygen to be reduced in the wetland environment which makes it important for the oxidation of organic matter (Table 1) (Mitsch and Gosselink 2000). It is important for development and growth for a variety of plant processes (i.e. photosynthesis and carbohydrate use), including uptake of other nutrients (Brady and Weil 2008). However much of the N in soils is largely not plant-available without microbial transformation in the rhizosphere or oxidized soil layer. These transformations also remove excess nitrates from the soil solution through denitrification and plant assimilation (Mitsch and Gosselink 2000; Hossler and Mitsch 2004; Brady and Weil 2008).

1.4.2.2.2 Carbon to Nitrogen Ratio (C:N)

C:N is an indication of OM decomposition and stabilization (Nair et al. 2001; Brady and Weil 2008). Different types of organic litter have different levels of ratios of C:N , and so OM amendments added to sites must be chosen carefully. Detritus with high C:N can typically can range > 100s:1 (i.e., sawdust, newspaper) while better quality detritus contains a C:N range of 15:1 to about 30:1 (i.e., grass or compost) (Brady and Weil 2008).

OM with high C:N have relatively low palatability due to high C-content and immobilized nitrogen. The low N levels will also cause microbes to supplement N from the soil solution which will cause a *nitrate depression* whereby N is unavailable to vascular plants. OM characterized by low C:N provides this necessary N for microbes, which maintains soil N. As a result, a nitrate depression does not occur, and nitrate soon becomes plant-available (Brady and Weil 2008).

Newer soils, such as those implanted into created wetland sites, typically have high C:N levels. It is only once the soils have been transformed by microorganisms that the levels decrease. Typical C:N ratios of created wetland soil are between 15:1 to 25:1 (Nair et al. 2001).

1.4.2.2.3 Total Iron

Iron is important for chlorophyll formation and is used in enzymes, especially those used for redox transformations (Brady and Weil 2008). Oxidized (ferric) iron displays a characteristically bright red color as iron oxides that coat the soil particles in aerobic conditions. Under anaerobic conditions, reduced (ferrous) iron is removed from the soil particles, due to its higher solubility (Brady and Weil 2008). This leaves the gleyed, gray matrix typical of wetland soils (Mitsch and Gosselink 2000; ACOE 2008; Brady and Weil 2008; USDA NRCS 2010). Ferric iron can be reformed along the rhizosphere as iron plaques and exert influence on the mobility of P (Weiss et al. 2003; Neubauer et al. 2007).

1.4.2.2.4 Total Phosphorus

Phosphorus is essential for optimal plant growth, functioning in photosynthesis, reproduction and maturation, N-fixation, and root growth (Brady and Weil 2008). Phosphate can be deposited in wetlands as particulates, or dissolved P can adsorp to clay particles (Klapproth and Johnson 2000). By being retained by colloids and oxides, inorganic P can become desorbed to the soil solution, and made available to plants as phosphate ions. Organic P is the more valuable form to flora and is mineralized from decomposing OM (Brady and Weil 2008). Its availability generally increases in hydric soils, but it can be precipitated out by equally available iron (Mitsch and Gosselink 2000).

The soil of a created wetland must be given time to weather and allow plants to both incorporate and reconstitute the soil P from inorganic to organic. With time, and the increase of organic P from vegetative litter, vegetative species diversity can increase to include species that require higher levels of organic P.

Human activities have contributed large amounts of P to the natural environment (agriculture, waste treatment, etc) which have resulted in heavy system nutrient enrichment (Mitsch and Gosselink 2000; Hogan et al. 2004; Brady and Weil 2008). Excess nutrients are removed by transformations in wetland soil systems which may then prevent eutrophication in sensitive systems.

1.4.3 Hydrophytic Vegetation Criteria and Indicators

Hydrophytic vegetation are species adapted to living in saturated or inundated soils (Tiner 1996; Mitsch and Gosselink 2000; Dahl 2006; ACOE 2008) that possess some morphological, physiological, or reproductive characteristics that have enhanced their survival and ability to out-compete other species (i.e. pneumatophores, enhanced P uptake). Since vegetation may respond to both soil and hydrologic conditions, vegetation may help researchers determine if the wetland is successful overall (Atkinson et al. 1993), although Reinartz and Warne (1993) do not recommend using vegetation as an indicator of function.

Vegetative communities are defined by the dominant species at the given site, which are those that are the most abundant (Tiner 1999). Similarly, the 50/20 rule states that > 50% of the total cover of the most abundant species, or ≥ 20% of the cover individually, in any particular stratum (i.e. herbaceous, shrub) is considered to be dominant (Tiner 1999; Mitsch and Gosselink 2000; ACOE 2008).

Plant species have been assigned an indicator (WI) as a measure of their affinity to wetland conditions (USFWS; Tiner 2006; ACOE 2008). Species with the status of obligate wet (OBL), facultative wet (FACW), or facultative (FAC) assignments refer to these species adapted to living in anaerobic soils. When combined with hydrologic and biogeochemical indicators, a determination of > 50% wetland designated dominant species identifies the site as a wetland (USFWS; Norfolk District Corps and VDEQ 2004; ACOE 2008).

Biological development along a theoretical trajectory gradient is based upon the basic tenants of ecological succession as defined by Odum (1969). Accordingly, the community of vegetation is said to develop in both a conventional and directional manner culminating in some maximum biomass. As a result, woody vegetation can be expected to culminate the development of created wetlands. However, the time frame in which this may occur may never be fully understood (Mitsch and Gosselink 2000).

Indicators of hydrophytic vegetation in the Coastal Plain Region (ACOE 2008):
The following indicators should be applied in the sequence presented. The stepwise procedure is designed to reduce field effort by requiring that only one indicator, the dominance test, be evaluated in the majority of wetland determinations. Hydrophytic vegetation is present if any of the indicators is satisfied.

1. Apply Indicator 1 (Dominance Test).
    a. If the plant community passes the dominance test, then the vegetation is hydrophytic and no further vegetation analysis is required.
    b. If the plant community fails the dominance test, and indicators of hydric soil and/or wetland hydrology are absent, then hydrophytic vegetation is absent unless the site meets requirements for a problematic wetland situation.
    c. If the plant community fails the dominance test, but indicators of hydric soil and wetland hydrology are both present, proceed to step 2.
2. Apply Indicator 2 (Prevalence Index of three or less).
   This step assumes that at least one indicator of hydric soil and one primary or two secondary indicators of wetland hydrology are present.
    a. If the plant community satisfies the prevalence index, then the vegetation is hydrophytic. No further vegetation analysis is required.
    b. If the plant community fails the prevalence index, then hydrophytic vegetation is absent unless indicators of hydric soil and wetland hydrology are present and the site meets the requirements for a problematic wetland situation.

1.5 *WETLAND MITIGATION*

As previously mentioned, when avoidance of wetland impacts is impossible, in accordance with the policy of "no-net-loss," developers must mitigate these wetland impacts with preservation, restoration, or creation of unrelated sites. While preservation, through the purchasing of natural wetland area, does not increase the total area of wetland area and instead perpetuates net loss, it does allow for the protection of wetland area for future generations. Restoration involves the conversion of a site that was historically wetland environment, but was converted for anthropogenic usage, back to wetland area. This requires the re-establishment of wetland hydrology which then alters the now aerobic soil and upland-type vegetation back to hydrophytic and anaerobic types.

Wetland creation occurs when a site is constructed where a wetland has never stood historically. A cut site is created by removing the upper horizons of an upland environment down to the level of the water table, so that the hydrology can affect the aerobics of the surface of the soil solution. A filled site involves the placement of soil in order to raise the soil surface to an adequate level for both soil and vegetative development. Inland systems that are not regulated by tides (i.e., non-tidal, palustrine) are much more difficult to recreate (Whigham 1999) and these types constitute 80% of all impacted systems (Mitsch and Gosselink 2000). Of these, palustrine forested wetlands are one of the most commonly disturbed and most difficult to recreate (Kusler and Kentula 1989), due to a variety of factors, including the developers lack of experience in wetland creation (Mitsch and Gosselink 2000).

Ecological adaptation through self-design should be promoted through created wetland development (Mitsch and Gosselink 2000). This means that created wetlands should be designed in a way that is conducive to development in the desired direction (i.e., forested versus emergent sites), while simultaneously allowing for natural fluctuations. Similarly, there exists a significant need for adaptive management techniques in wetland creation (Palmer et al 2005). Sites must be created with the opportunity to deal with system uncertainty, and managers must adapt management based on data from monitoring system performance. Finally, conclusions derived from site construction and monitoring methods must be made available to the public, in order to insure that future managers are enabled with previous resolutions (O'Donnell and Galat 2008). This would ensure that managers can continue to improve mitigation and restoration sites.

Researching baseline data at mitigation sites through pre- and post-construction, as well as utilization of control or reference sites, is crucial for making better qualitative and quantitative assessments as to the environmental success of wetland characteristics over time (ACOE 2004; Norfolk District Corps and VDEQ 2004; Palmer et al. 2005; O'Donnell and Galat 2008).

Overall, it appears that total wetland area has begun to increase through mitigation, and rate of wetland area loss has slowed (Dahl 2006). However, this does not reference the quality or functional status of sites. In fact, many higher order wetlands are being converted to lower classified systems (i.e., forested sites converted to herbaceous dominated sites) (Kihslinger 2008). Dahl (2006) found that ponded area increased substantially (12.6%) by 2004, and that little palustrine forested wetland area was gained between 1998 and 2004. What was acquired was due to shrub maturation.

In order to better guarantee future functional success of sites, the EPA and the ACOE began to rely more on wetland mitigation banking (WMB) (Mitsch and Gosselink 2000; Salzman and Ruhl 2006). WMBs are larger entities produced off-site where developers can purchase credits and avoid compensation construction on their own. Theoretically, in this way, integrity of ecological function can be better guaranteed in the larger lots, rather than smaller more isolated sites. However even WMBs have been subject to debate about their overall functional success (Mack and Micacchion 2006).

Overall, much of the wetland area included in the total for "no-net-loss" arises from off-site WMBs rather than on-site compensatory efforts (Salzman and Ruhl 2006), which may result in a loss of functional assets in areas where wetlands historically stood.

1.6 *PROPERTIES OF MITIGATION WETLANDS*

Overall, functional wetland recreation has proven troublesome (NRC 2001). The literature agrees that more research must be performed in order to better develop created systems since there exists so much uncertainty as to the potential for functional equivalency with mitigated sites. Additional research is crucial for evaluating the key attributes of wetlands where created sites seem to fail the most: hydrology, MSPD, and organic matter content. Studies have stressed the importance of modeling developmental trajectories of growth in order to better evaluate the potential for directional growth analogous to natural site characteristics (Zedler and Callaway 1999; Windham et al. 2004; Giese and Flannagan, unpublished data).

1.6.1 Hydrologic Properties of Mitigation Wetlands

Proper hydrologic design is the backbone to proper created wetland development since it leads to proper biogeochemical soil formulation, which in turn affects vegetative development (Mitsch and Gosselink 2000).

Similar to the transitional nature of a wetland between an upland and aquatic environment, so must there exist a transition between palustrine wetland and the surrounding environment (Mitsch and Gosselink 2000). Mitigation credit is not given to this transitional area which, in some cases, results in the creation of sites with steeper than recommended slopes. This coincides with the perception in the United States that created sites should show the presence of standing water (Streever 1999). As a result, the basin morphology of many mitigation wetlands can best be described as "bathtub" inspired, (Whittecar and Daniels 1999; Pennington and Walters 2006).

Studies have shown mixed hydrologic success in wetlands. Many mitigation sites end up having water levels that are too high (Stolt et al 2000; NRC 2001), or too low (Pennington and Walters 2006). Sites in Michigan were historically designed with high water levels to ensure permit compliance (Pennington and Walters 2006). Many Eastern Virginia VDOT mitigation sites also end up being "too wet" or "too dry" (Whittecar and Daniels 1999), often due to insufficient site hydrologic evaluations prior to construction.

1.6.2 Soil Properties of Mitigation Wetlands

Created wetland soils have been shown to lag in rates of development when compared to natural reference wetlands (NRC 2001). Due to compaction by heavy machinery during construction, created sites tend to have higher MSPDs (Whittecar and Daniels 1999; Nair et al. 2001; Hogan et al 2004; Norfolk District Corps and VDEQ 2004; Brooks et al. 2005; D'Angelo et al. 2005; Fajardo 2006; Bailey et al. 2007), and lower porosity (Fajardo 2006). Similarly, created sites were characterized by sandier textures (Bishel-Machung et al. 1996; Stolt et al. 2000; Fajardo 2006), and lower levels of organic matter relative to natural reference sites (Atkinson et al. 1993; Bishel-Machung 1996; Whittecar and Daniels 1999; Nair et al. 2001; Hogan et al 2004; Brooks et al. 2005; D'Angelo et al. 2005). Incorporating microtopography (pits and mounds) into construction has been recommended to both mitigate some minor issues in hydrology, better mimic wetland conditions, and create a heterogeneous soil and microclimatic environments (Whittecar and Daniels 1999; Stolt et al 2000; Pennington and Walters

2006). This has the potential to increase species richness (Bruland and Richardson 2005; Moser et al. 2007).

Created sites were shown to be lacking proper soil biogeochemical conditions (Bailey et al. 2007), more specifically the essential nutrient levels necessary for plant and microbial development. Natural sites contained more % C (Nair et al. 2001; Giese and Flannagan, unpublished data), more total N (Nair et al. 2001; Hogan et al 2004; Giese and Flannagan, unpublished data), more % P (Nair et al. 2001; Hogan et al 2004), and more % Fe (Nair et al. 2001).

However, many studies have also shown that these characteristics slowly began to change over time in the direction towards increasing similarity to natural reference sites. Giese and Flannagan (unpublished data) found that eight created sites contained increased levels of %OM, %N, and %C increased by the fourth growing season, while C:N correspondingly decreased. The ratio of C:N appeared to be equitable to that of natural reference sites by the end of the third growing season. Nair et al. (2001) similarly found that with increasing age, MSPD and C:N decreased, and Total C increased at created sites. Hossler and Mitsch (2004) reported an overall decrease in chroma at sites which equates to a 24% increase in hydric soil at the surface layer, and Vepraskas et al. (1999) reported that soil chroma changes of an entire unit can be seen within one year's time. Many studies are showing evidence of positive changes towards becoming wetland soils; however the timeline for how long this should take is still not fully understood (Windham et al. 2004; Daniels et al. 2005; Giese and Flannagan, unpublished data; Fajardo 2006).

1.6.3 Vegetative Properties of Mitigation Wetlands

Due to inadequate time to develop, wetland vegetation at very young created sites tends to be lacking in species diversity, richness, and maturing successional species (Fajardo 2006) relative to reference wetlands. Species diversity tends to increase in older created sites, and overall, has been found to be greater than at the more mature natural wetlands (Balcombe et al. 2005), where each niche is otherwise defined (Cowardin et al. 1979). Percent cover of vegetation was found to be similar to reference sites after only a few years of development (Balcombe et al. 2005).

Self-design, according to Mitsch and Gosselink (2000), is defined as ecosystem development where the introduction of floral and faunal species and their subsequent survival or nonsurvival provides the essence of a site's development. It allows natural successional patterns to take course based on the success or failure of the hydrogeomorphic setting of the site. In this way, developers are able to introduce woody species that have previously proven successful (Andreas and Lichvar 1995; Mitsch and Gosselink 2000; USGS 2002; Tiner 2006; Natural Resources Conservation Service 2007; ACOE 2008; Environmental Concern 2008) into sites and given the opportunity to flourish or falter. Reinartz and Warne (1993) and Balcombe et al. (2005) recommend introducing native species diversity early to ensure the long-term diversity of the sites. Mitsch et al. (1998) saw similar results in diversity between a control and sample site six years after planting.

Other studies have similarly shown that given appropriate hydrologic and soil conditions, hydrophytic vegetation was likely to establish itself early in mitigation site development, often within three to five years after construction (Confer and Niering

1992; Brown 1999). For the first ten years, species diversity may suffer and volunteer species may be comprised of non-native types (National Research Council 2001), but with time, it is expected that these volunteers will be competitively excluded (Balcombe et al. 2005).

Chapter 2. Vegetation and Physical Soil Characteristics

2.1 *METHODS*

Daniels et al. (2005) and Fajardo (2006) investigated the relative quality and success of created non-tidal compensatory mitigation forested wetlands within the Coastal Plain and Piedmont Provinces of Virginia by measuring environmental variables. Sites selected for their studies were all recently constructed (i.e., post 1998) wetlands mitigating VDOT construction, that were six to ten years old for my study. The sites were designed to replace palustrine forested wetland sites, and had been constructed with a variety of different soil reconstruction approaches (i.e. cut or fill, organic matter amended or un-amended sites) (Table 2, 3, 4).

The researchers had input from the VDOT Environmental Division and background research histories for each site. Other important factors for selecting these sites were the previous experience and knowledge of principal investigators regarding each of the sites as well as the presence of reference wetlands that were adjacent to each site. The soil at each reference site had never been disturbed, but vegetation had been disturbed relative to the sites' ages (i.e., a 37-year-old reference site was disturbed 37 years ago). Reference site data for Dick Cross and Stony Creek sites were unavailable. Natural reference sites ranged in age from 37 years old at the reference to Mt. Stirling to 82 years old at the reference for SW Suffolk. Descriptions of these sites can be found in DeBerry (2006).

Fajardo (2006) assessed each of the selected sites for hydric soil indicators and reported encountered vegetative species. Daniels et al. (2005), a summary report, encompassed data from Fajardo (2006) and other studies to evaluate these sites for a full range of soil, hydrologic, and vegetative characteristics in order to assess the sites for permit compliance. The previously documented sites common to those studies and the present study are listed in Table 2, and identified by location in Figure 1. Individual site soil preparation methods are laid out in Table 3. General vegetative and planning site descriptions are listed in Table 4.

2.1 *Site Descriptions*

Table 2: Nine selected VDOT sites used in this study. Site size, age, location, and mitigation cause. For further directions to the sites see Appendix 5.2.

Site Name (Abbreivation)	**Figures**	**Initial Construction**	**Size (ha)**	**Latitude & Longitude**	**Region**	**Construction Compensation**
Charles City (CCW)	2a, b 30a-d	1998	20.78	37.34359° N, 76.92788° W	VA Coastal Plain	Route 199 in Williamsburg
Dick Cross (DC)	3a, b 31a-d	2000	10.45	36.61657° N, 78.27222° W	VA Piedmont	Partial mitigation for expansion of State Route 58 and construction of the State Route 1 Bridge over the Roanoke River
Manassas (MAN)	4a, b 32a-d	1999	15.87	38.72294° N, 77.50565° W	VA Piedmont	Construction of State Route 234 Bypass
Mattaponi (MATTA)	5a, b 33a-d	2001	8.41	38.02204° N, 77.37701° W	VA Coastal Plain	(Mitigation Bank) Multiple points of impact to non-tidal portions of the York River watershed
Mt. Stirling (MTS)	6a, b 34a-d	1999	13.00	37.42033° N, 77.03699° W	VA Coastal Plain	Construction of the Interstate 95 Atlee Elmont Interchange Bypass
Reedy Creek (RCK)	7a-e 35a-d	2001	18.22	37.32275° N, 77.78963° W	VA Piedmont	Construction of Route 288
Sandy Bottom (SB)	8a, b 36a-d	2002	19.43	37.06745° N, 76.43797° W	VA Coastal Plain	Construction of the Hampton Roads Center Parkway & expressway extension
Stony Creek (SCW)	9a, b 37a-b	1998	2.27	36.9437° N, 77.38267° W	VA Coastal Plain	Small maintenance and replacement projects
SW Suffolk/ Lake Kilby (SWS)	10a, b 38a-d	2002	5.02	36.71807°N, 76.61992°W	VA Coastal Plain	Construction of the SW Suffolk Bypass

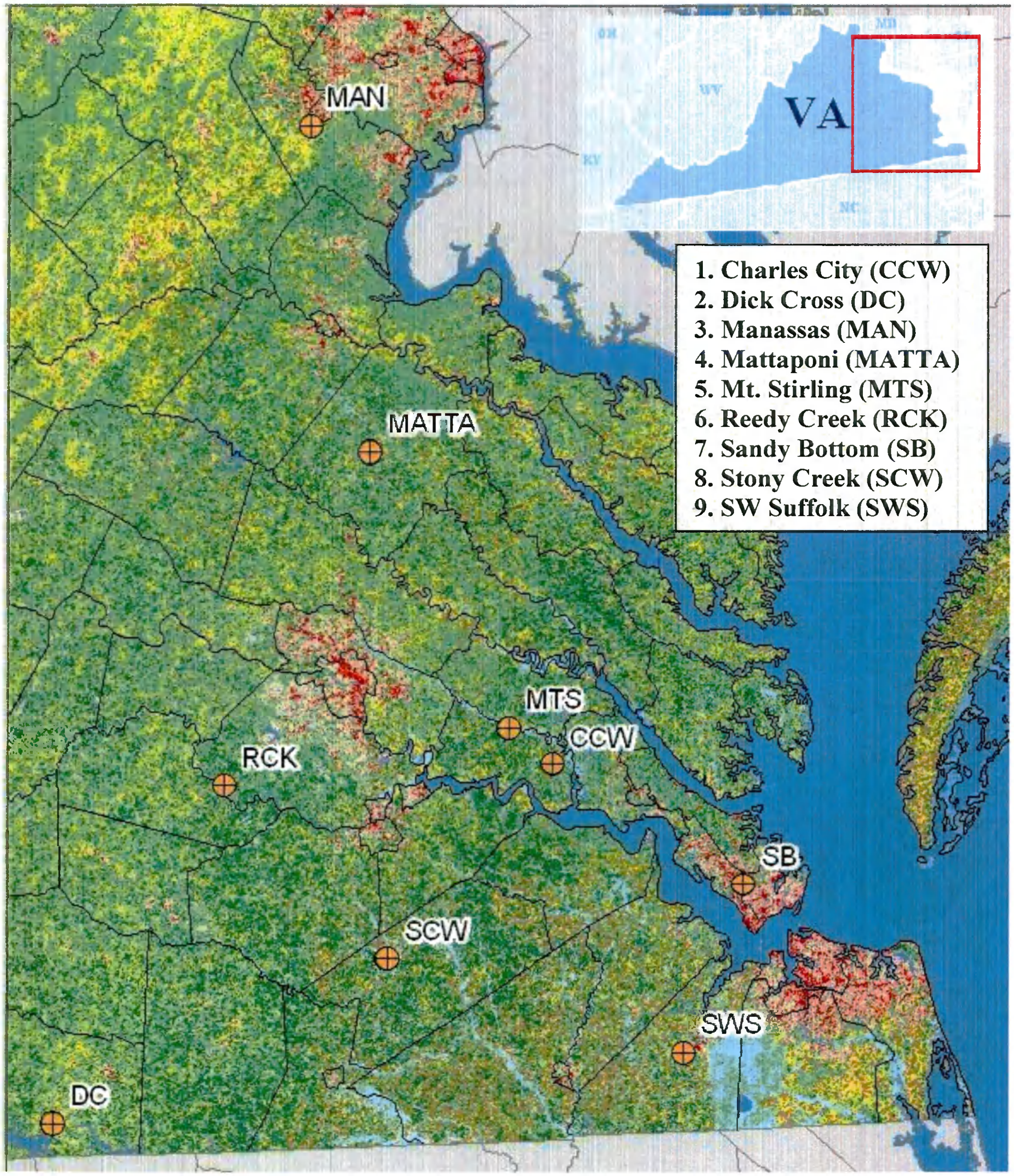

Figure 1: Locations of VDOT sites included in this study.

Table 3: Soil Construction Methods for the Nine selected VDOT sites in this study. Soil classification and in-depth construction details, were outlined in previous studies (Fajardo 2006; Daniels et al. 2005).

Site	Soil Sampling Dates (site age in years) Fajardo Kreisel	Construction Method: Depth (m)	OM / Lime / Fertilizer Applied?	Ripped / Disked?	Returned Topsoil Depth (cm)
Charles City (CCW)	4/2002 (4) 1/2009 (10)	Cut: 0.6 - 0.9	Post Fajardo sampling/ Yes/ No	Yes / Yes (15 cm)	2 - 8
Dick Cross (DC)	8/2002 (2) 1/2009 (8)	Cut: 0.6 - 0.9	No/ Yes/ Yes	No / Yes (15 cm)	15
Manassas (MAN)	7/2002 (3) 1/2009 (9)	Cut: 0.56	No/ Yes/ Yes	No / Yes	Unknown depth
Mattaponi (MATTA)	5/2002 (1) 1/2009 (7)	Cut: 0.6 - 1.2	Yes 4%/ Yes/ Yes	No / Yes (15 cm)	30
Mt. Stirling (MTS)	10/2003 (4) 1/2009 (9)	Cut: 0.8 - 0.9	No/ No/ Yes	Yes (not deep) / Yes (15 cm)	15
Reedy Creek (RCK)	3/2004 (3) 1/2009 (7)	Cut: 0.3 - 0.9	Yes (Old site Veg.)/ Yes/ Yes	Unknown / Yes (15 cm)	30
Sandy Bottom (SB)	8/2003 (1) 11/2008 (6)	Fill	Yes 4%/ Yes / unknown	No (Yes post 2003 sampling) / Yes (20 cm)	15
Stony Creek (SCW)	7/2002 (4) 9/2008 (10)	Fill	Yes/ Yes/ Yes	No / Yes (15 cm)	10
SW Suffolk/ Lake Kilby (SWS)	4/2004 (2) 1/2009, 2/2009 (6)	Fill	Yes 4% / Yes / Yes	No / Yes	Unknown depth

Table 4: General vegetative and planning site descriptions for each of the nine sites in this study. In-depth construction details, were outlined in previous studies (Fajardo 2006; Daniels et. al 2005).

Site	Planting Date	No-Net-Loss Planning Efforts	Planted Woody & Shrubby Vegetation	Vegetation Sampling Dates <u>(site age in years)</u> Fajardo Kreisel
Charles City (CCW)	Spring 2004	88% forested 6% scrub-shrub 6% emergent	*Betula nigra* *Cephalanthus occidentalis* *Quercus palustris* *Quercus pagodaefolia* *Quercus phellos,* *Rosa palustris* *Taxodium distichum*	4/2002 <u>(4)</u> 6/2008, 9/2008 <u>(10)</u>
Dick Cross (DC)	August 2003	75% forested 22% scrub-shrub 3% emergent	*Betula nigra* *Cephalanthus occidentalis* *Cornus amomum* *Hibiscus moscheutos* *Quercus bicolor* *Quercus nigra,* *Quercus phellos*	8/2002 <u>(2)</u> 6/2008, 9/2008 <u>(8)</u>
Manassas (MAN)	May 2000	68% forested 8% scrub-shrub 24% emergent	*Alnus serrulata* *Cephalanthus occidentalis* *Fraxinus pennsylvanica* *Quercus palustris* *Quercus phellos* *Rosa palustris* *Salix nigra*	7/2002 <u>(3)</u> 6/2008, 9/2008 <u>(9)</u>
Mattaponi (MATTA)	May 2003	50% forested 25% scrub-shrub 25% emergent	*Alnus serrulata* *Betula nigra* *Carpinus caroliniana* *Cephalanthus occidentalis* *Fraxinus pennsylvanica* *Quercus phellos* *Hibiscus moscheutos* *Ilex decidua*	5/2002 <u>(1)</u> 6/2008, 9/2008 <u>(7)</u>
Mt. Stirling (MTS)	January 2003, & early 2004	74% forested 24% scrub-shrub 2% emergent	*Acer rubrum* *Betula nigra* *Ilex verticillata* *Quercus nigra* *Photinia pyrifolia* *Salix nigra* *Vaccinium corymbosum*	10/2003 <u>(4)</u> 6/2008, 9/2008 <u>(9)</u>

Table 4 continued

Site	Planting Date	No-Net-Loss Planning Efforts	Planted Woody & Shrubby Vegetation	Vegetation Sampling Dates (site age in years) Fajardo Kreisel
Reedy Creek (RCK)	Winter 2005	86% forested 2% scrub-shrub 12% emergent	*Acer negundo* *Carpinus caroliniana* *Cephalanthus occidentalis* *Quercus bicolor* *Salix nigra* *Rosa palustris* *Sambucus nigra ssp. canadensis*	3/2004 (3) 6/2008, 9/2008 (7)
Sandy Bottom (SB)	Fall 2004	90% forested 1% scrub-shrub 4% emergent	*Alnus serrulata* *Nyssa aquatica* *Photinia pyrifolia* *Quercus lyrata* *Quercus phellos* *Taxodium distichum* *Viburnum dentatum*	8/2003 (1) 6/2008, 9/2008 (6)
Stony Creek (SCW)	September 1999	86% forested 14% emergent	*Betula nigra* *Salix nigra* *Quercus palustris* *Taxodium distichum*	7/2002 (4) 6/2008, 9/2008 (10)
SW Suffolk/ Lake Kilby (SWS)	Fall 2003	85% forested 9% scrub-shrub 6% emergent	*Cephalanthus occidentalis* *Decodon verticillatus* *Nyssa aquatica* *Pinus seratina* *Quercus lyrata* *Rosa palustris* *Taxodium distichum*	4/2004 (2) 6/2008, 9/2008 (6)

2.1.1 Charles City Wetland (CCW)

Prior to being a created wetland, CCW was partially forested with small pines and the rest of the site was agricultural fields (D. Bova, VDOT, pers. comm.). The site is located near the Chickahominy River in Charles City County, VA (Figures 2, 39; Tables 2, 3, 4). Hydrology for the site is precipitation driven. Some of the site is underlain by a plow pan from agriculture and/or a traffic pan from construction which prevents some water from infiltrating into the soil. At some point between the two studies, CCW received major remediation. The site was re-graded, ditches were filled, a berm around the pond was created, and 5cm to 8cm of organic matter were added (L. Snead, VDOT, pers. comm.). The site is located in an agro-residential neighborhood. The site sits on land obtained from the farmer who owns the rest of the land in that lot. The site is bordered by forest, the farm, and a pond. Much of CCW was successfully comprised of hummocks and hollows to allow for variable microtopography . Some plots (CCW9, CCW10) were located in relatively dry soil.

2.1.2 Dick Cross (DC)

Part of DC is a restored site. The space was once a wetland, but had been converted for agricultural use (D. Bova, VDOT, pers. comm.). The site is located near the Allen Creek, a tributary of the Roanoke River in Mecklenburg County, VA (Figures 3, 40; Tables 2, 3, 4). Developers expected both groundwater and overbank flooding to maintain the hydrology at the site. DC is located more than a mile from developed areas, with the closest roads passing through sparse agro-residential neighborhoods. The site is segregated into three distinct regions, separated by a large berm which is wide and tall enough to drive across.

2.1.3 Manassas (MAN)

The site was previously used for farming operations. It was developed in a cut/fill manner. The site is located near Broad Run, a tributary of the Occoquan River in Prince William County, VA (Figures 4, 41; Tables 2, 3, 4). Hydrology was created at the site by the use of a soil saturation gradient resulting from two dams from the Cannon (North) and Cockrell Branch (East), which enter the site. Sporadic neighboring streams and groundwater were expected to maintain the hydrology at the site. At some point between the two studies, MAN received *Typha sp.* and water level management in the form of unclogging drainage pipes (L. Snead, VDOT, pers. comm.).

MAN is located near larger roadways in a semi-commercial area. It is also located across a stream from the Manassas regional airport. Helicopters and planes flew overhead at a low altitude creating higher than average noise disturbance areas. Manassas' plots ring a small lake with a driving berm that surrounds the site.

2.1.4 Mattaponi (MATTA)

The site is located on the Mattaponi River in Caroline County, VA (Figures 5, 42; Tables 2, 3, 4). Hydrology is maintained from groundwater seepage and overflow from the nearby river. Prior to being a wetland MATTA was predominately active farmland, with some wooded areas. The site was created by deep-cutting. After being sampled in Fajardo (2006), the site was remediated by cutting a ditch and adding pipes in the weirs at the NE portion in order to control *Typha sp.*. Pipes were also added in the SW portion to drain as well (M. Haus, VDOT, pers. comm.). MATTA is located just past a residential area. It is near industrial roads and bordered by major CSX and Amtrak rail lines.

Mattaponi plots are surrounded either by upland or consistently inundated areas, all situated inside a bathtub-type design.

2.1.5 Mt. Stirling (MTS)

The site is located on the Chickahominy River in Charles City County, VA (Figures 6, 43; Tables 2, 3, 4). A large portion of it was created from converted farmland. As a result, hydrology was reestablished by removing the drain tiles and ditches. At the time of construction, it was expected that hydrology would be sustained by precipitation, groundwater, and runoff from the adjacent stream - Collins Run. MTS is located in an agro-residential neighborhood. The site is bordered by the property owners' farmland to the South and West, and undeveloped forested land and the Chickahominy River lie North and East of the site. Either a berm, or a stream with a forested border divide the site into four sections separating MTS2 from MTS3, and MTS4 from MTS5; and MTS7 from MTS8, respectively (Figure 6b).

2.1.6 Reedy Creek (RCK)

The site is located on the Appomattox River in Chesterfield County, VA (Figures 7, 44; Tables 2, 3, 4). Located on private property, water inputs are provided by groundwater and runoff from an adjacent, unnamed natural system. Prior to being a wetland, RCK was used for silvicultural purposes for younger regenerative pine stands. RCK is located approximately2km from River Road, which is a two-lane route through a wooded residential area. RCK is comprised of three main sections within a small valley with lakes, ponds, and heavily wooded areas. Section A (RCK12-14) is the most northeastern section which borders forest, emergent wetland areas, and a dirt road.

Section B (RCK 7-11) is just south of Section A, and is comprised of smaller sections (RCK8, RCK9 are distinct), separated by reference areas and ponds, and bordering the main dirt road. Section C (RCK1-6) is southeast of Section B, and is set farthest into the forest, and borders both forest and emergent wetland and lake area.

2.1.7 Sandy Bottom (SB)

The site is located in the Sandy Bottom Nature Park in Hampton, VA (Figures 8, 45; Tables 2, 3, 4), surrounded by walking paths and bridges for visitors to walk across. The park borders Interstate 64, which sits only about a couple hundred meters away. Plots are situated around a small key shaped pond. Prior to wetland creation, SB was used for sand mining for Interstate 64 (Daniels et al 2005; Fajardo 2006). As a result, elevation was reestablished by filling and grading the borrow pits, while allowing for microtopographic variation. Due to considerable dominance of invasives like *Lespedeza sp.* SB was partially remediated after being sampled in Fajardo (2006).

2.1.8 Stony Creek (SCW)

Prior to wetland creation, SCW (Figures 9, 46; Tables 2, 3, 4) was used for sand mining (Fajardo 2006). As a result, elevation and hydrology were reestablished by filling and grading the deep pond according to adjacent wetlands. Hydrology is maintained through seepage and stream overflow from the Stony Creek channel. SCW was the smallest of the sites, a small wetland forming an L around a pond normally a few feet deep. SCW sits directly off of State Road 40 in Sussex County, VA, and Interstate 95 is less than a mile away. A minor dirt road on the western border of the site runs to private property in the back, and a construction trailer (visible in Figure 19) sat idle on the SW corner of the site. State Road 40 receives a relatively low amount of traffic.

In the beginning of the 2008 growing season, the entire site was unsaturated. By the end of the growing season, water had risen to more than ~20cm. By wintertime, this depth had tripled and remained so into the next growing season (2009). As a result of this, field work was unable to be completed for this site. We were later informed by VDOT that beavers were making a home in the drainage pipe (D. Devereux, VDOT, pers. comm.), and this had been the cause of the water blockage.

2.1.9 SW Suffolk/Lake Kilby (SWS)

SWS is located on Lake Kilby in Suffolk, VA (Figures 10, 47; Tables 2, 3, 4), and was previously used for sand mining (Fajardo 2006). As a result, elevation was reestablished by filling and grading the borrow pits, and cutting the edges of the pits. At the time of construction, it was expected that hydrology be sustained by groundwater and surface flow. The site also receives runoff from the housing development. SWS is < 0.5 km from U.S. Route 13. A railroad sits approximately 1km away from the site both to the North and South, and the Suffolk municipal airport is only 3 km away. During field work, the dirt road surrounding the site was frequented by all-terrain vehicles (ATVs) from the adjacent residential neighborhood. A power line runs through the center of the site.

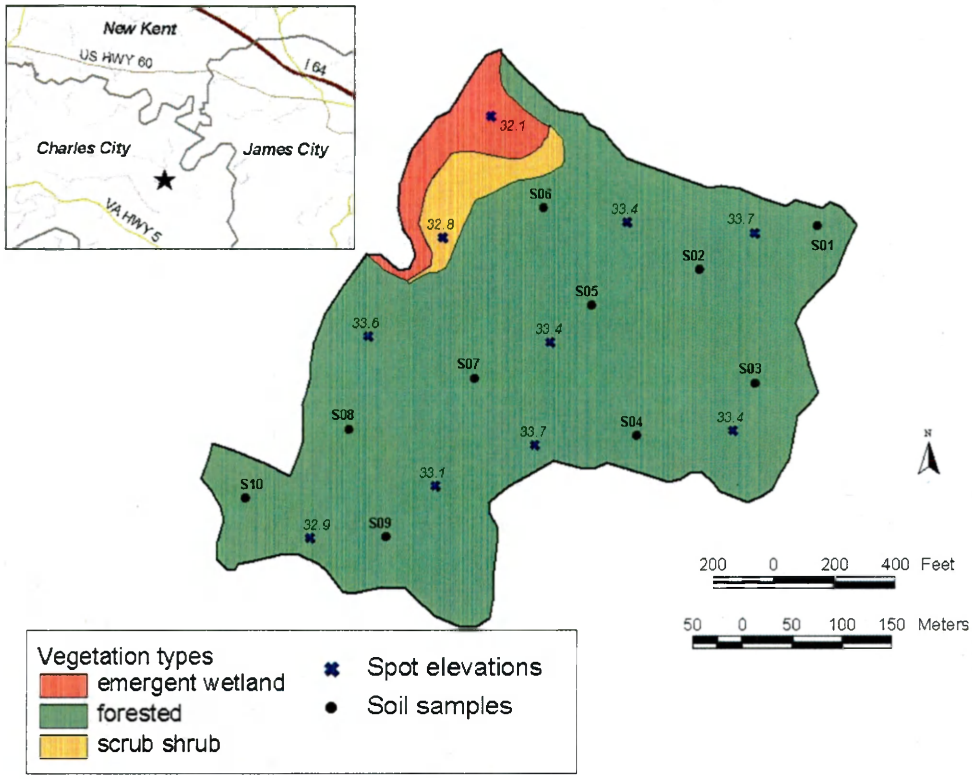

Figure 2a: Charles City (CCW) site map (Fajardo 2006).

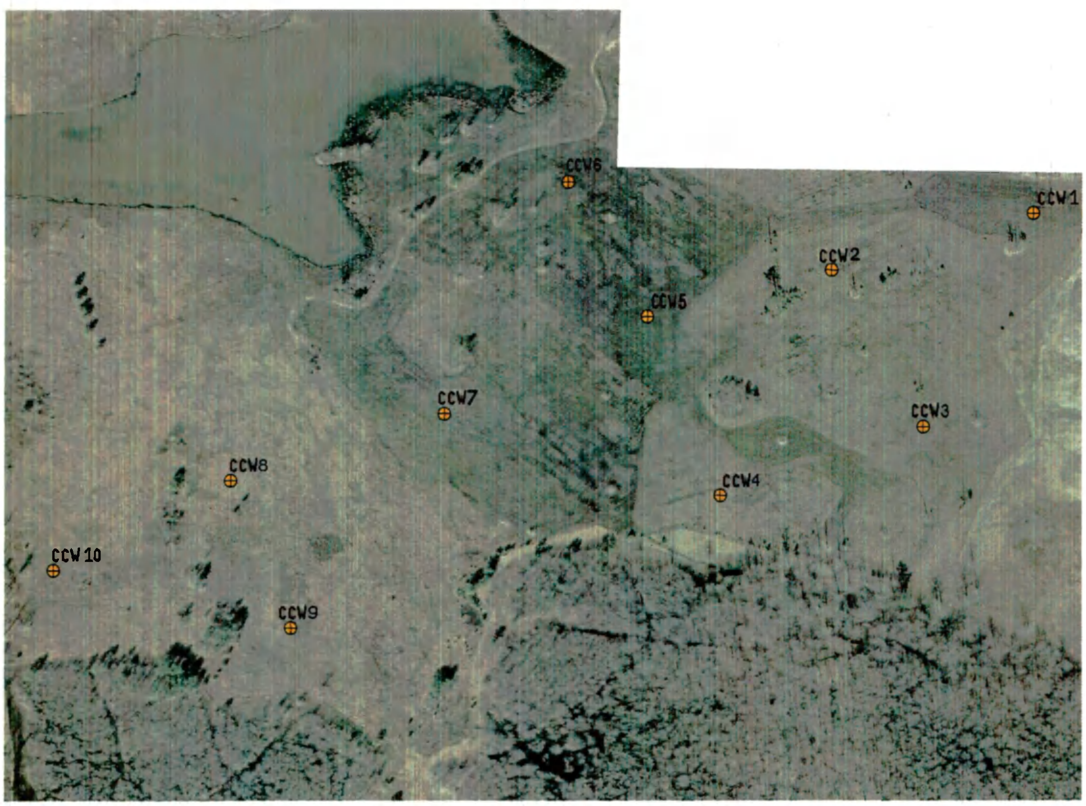

Figure 2b: Photo of Charles City (CCW) site.

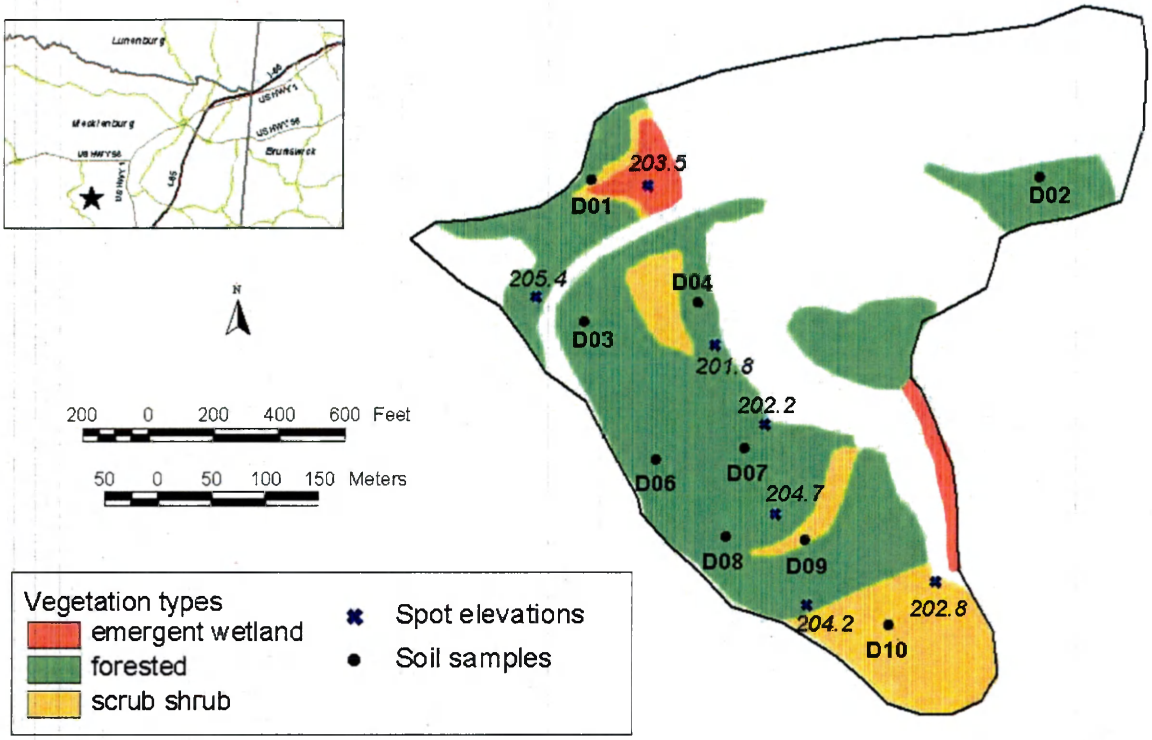

Figure 3a: Dick Cross (DC) site map (Fajardo 2006).

Figure 3c: Photo of Dick Cross (DC) site.

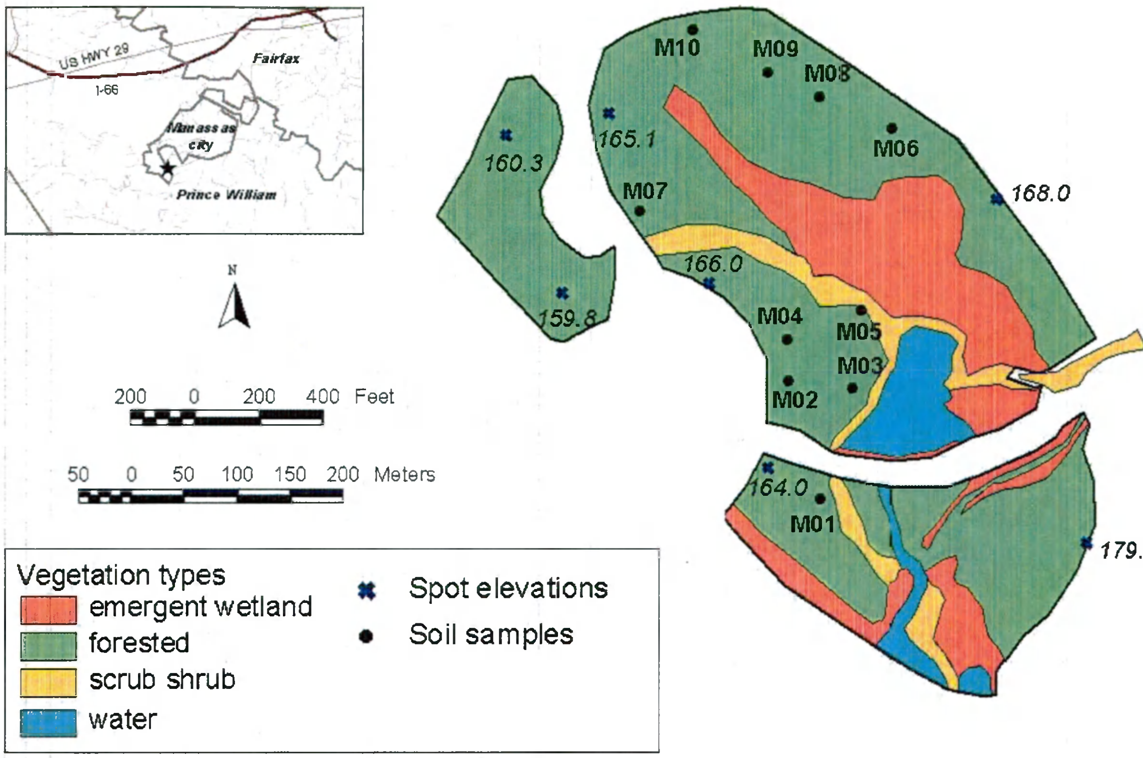

Figure 4a: Manassas (MAN) site map (Fajardo 2006).

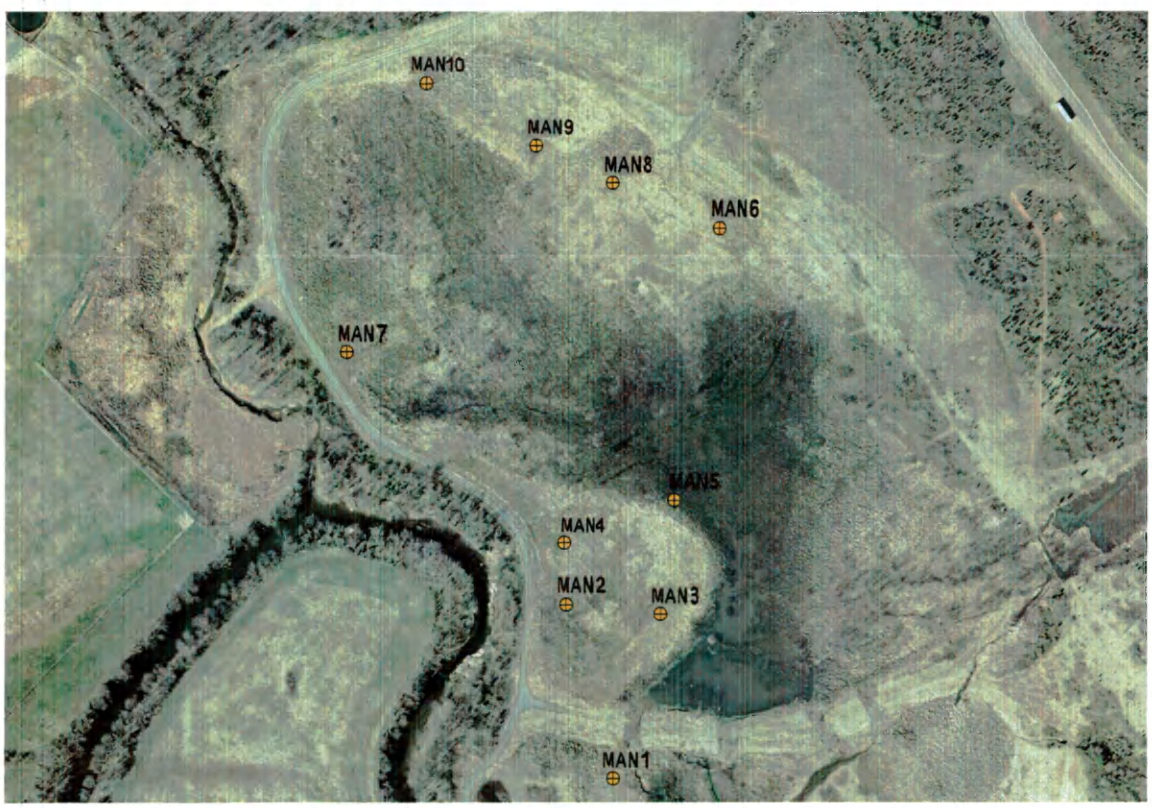

Figure 4b: Photo of Manassas (MAN) site.

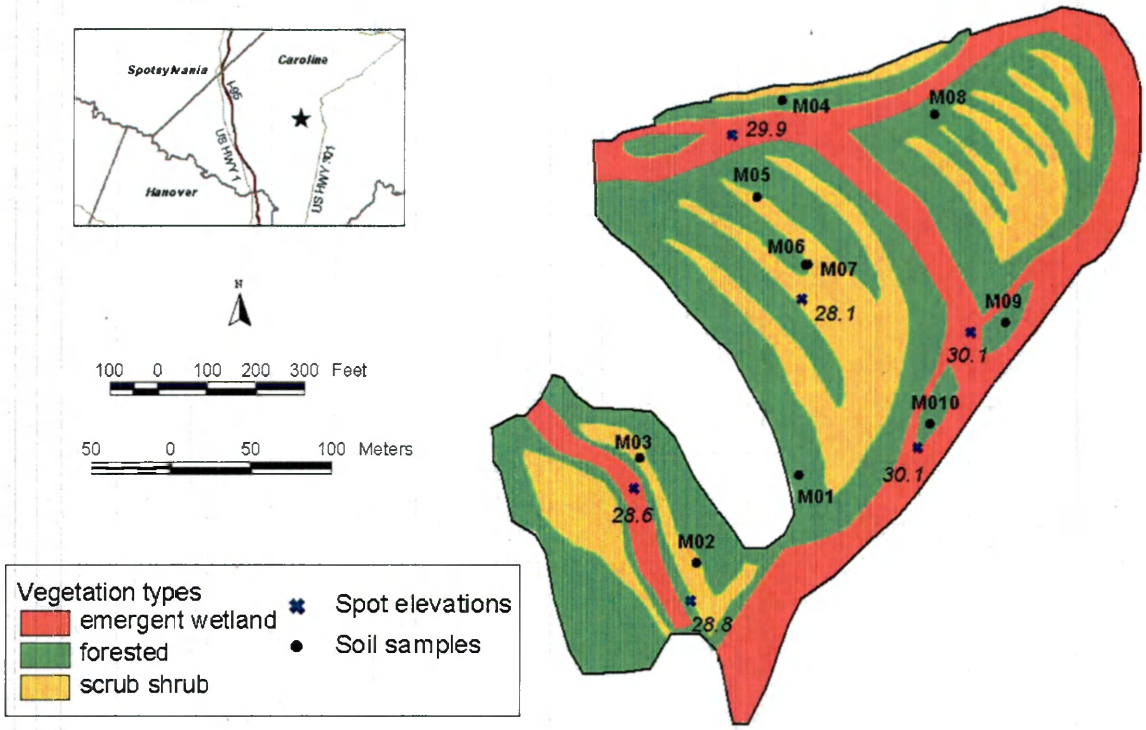

Figure 5a: Mattaponi (MATTA) site map (Fajardo 2006).

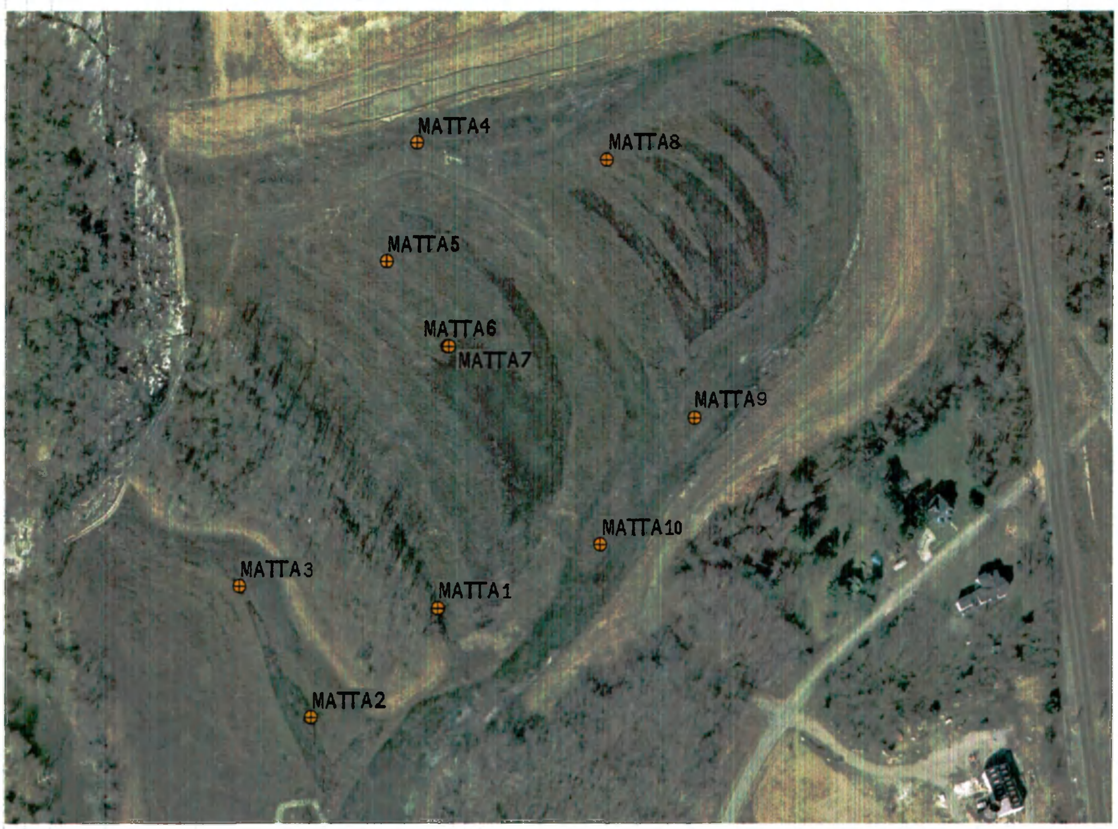

Figure 5b: Photo of Mattaponi (MATTA) site.

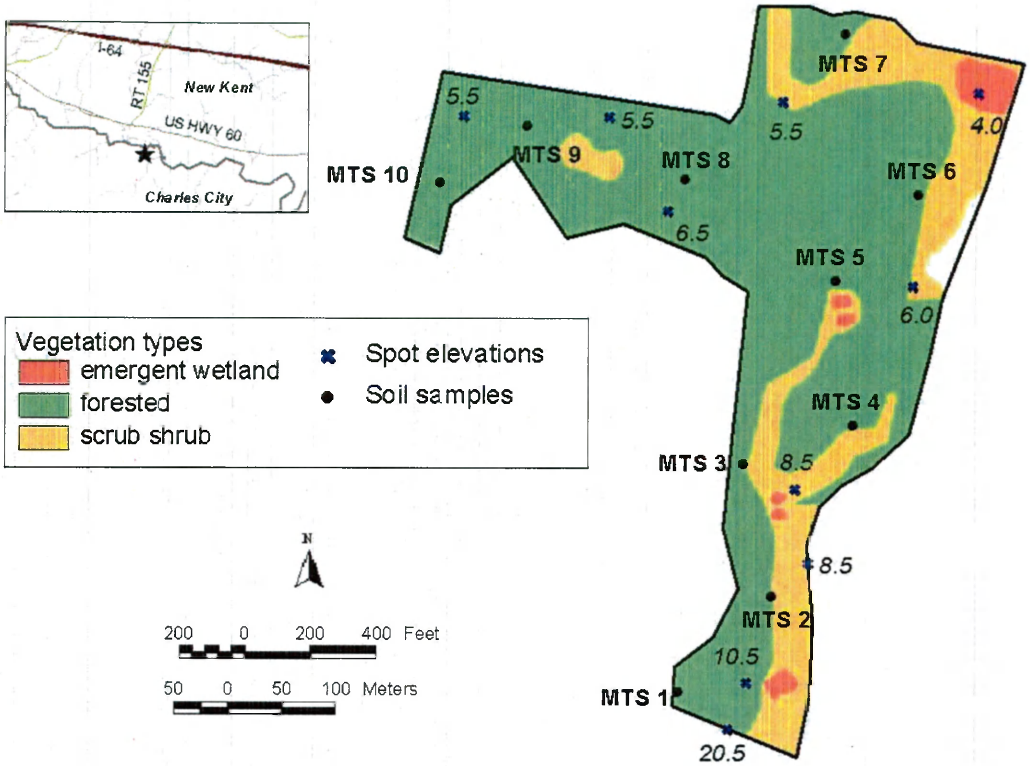

Figure 6a: Mount Stirling (MTS) site map (Fajardo 2006).

Figure 6b: Photo of Mount Stirling (MTS) site.

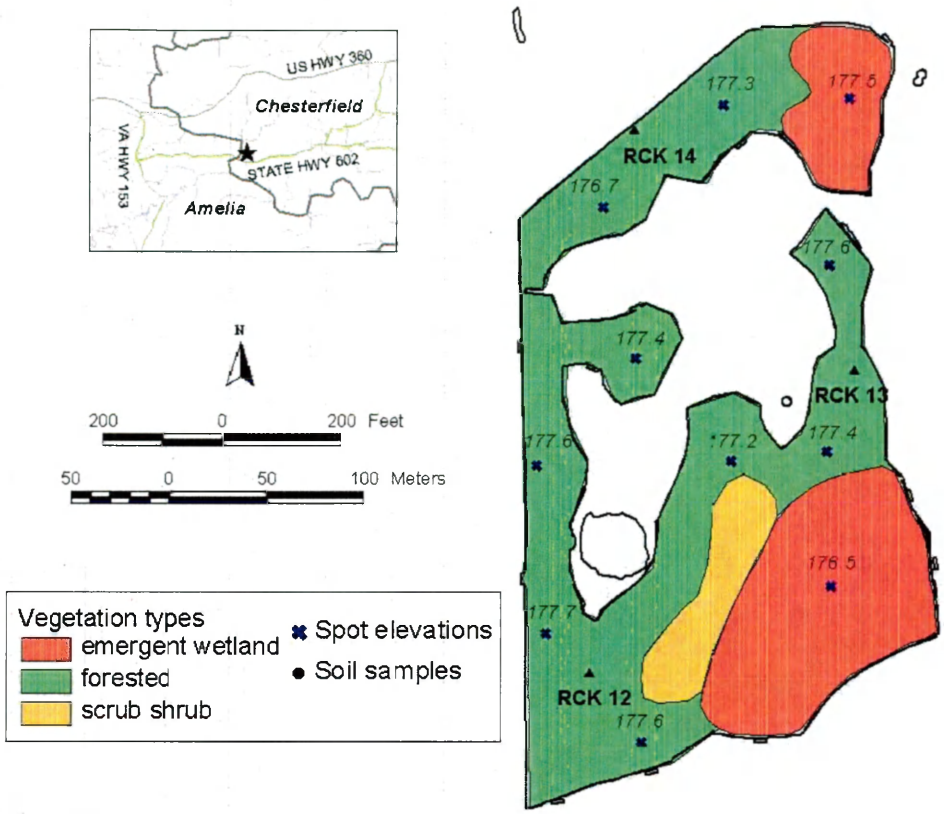

Figure 7a: Reedy Creek (RCK) site map - Section A (Fajardo 2006).

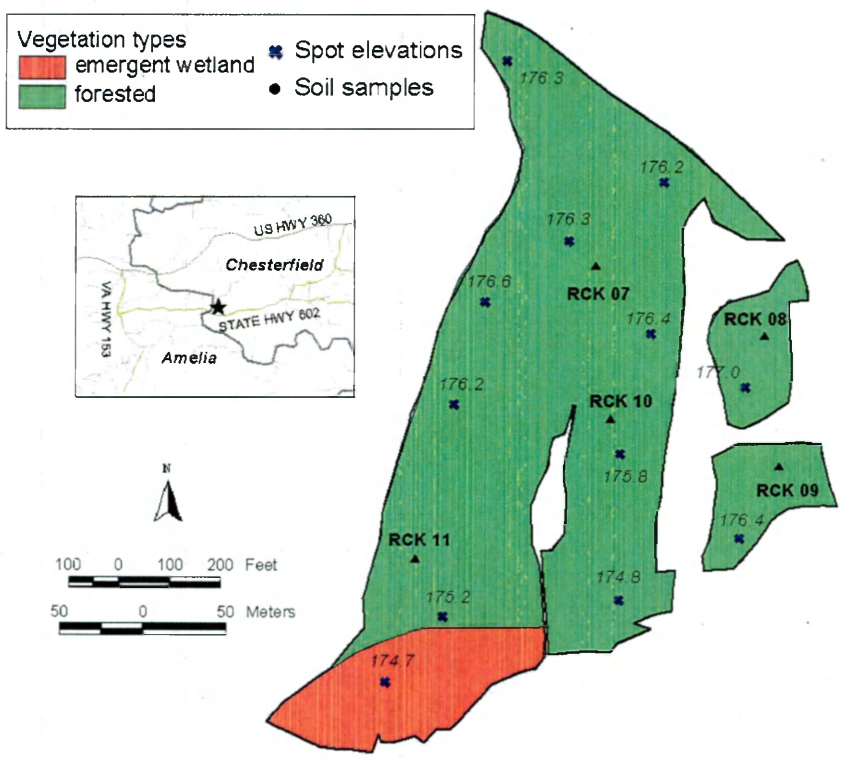

Figure 7b: Reedy Creek (RCK) site map - Section B (Fajardo 2006).

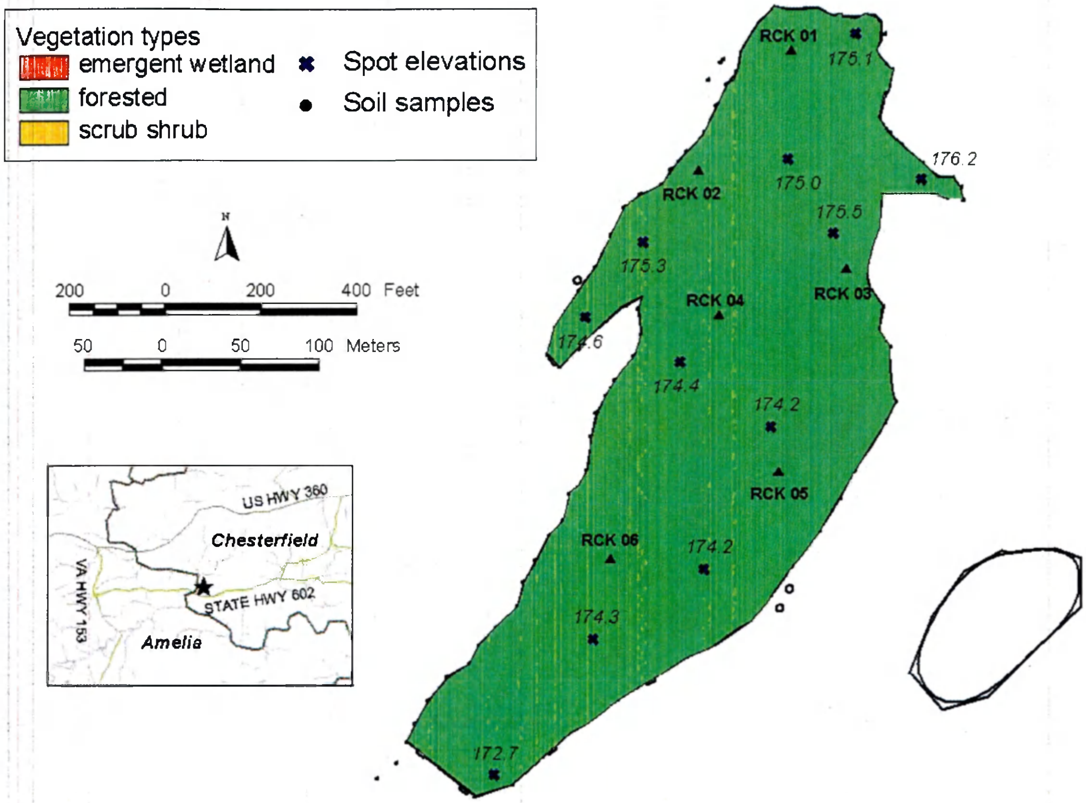

Figure 7c: Reedy Creek (RCK) site map - Section C (Fajardo 2006).

Figure 7d: Photo of Reedy Creek (RCK) site - Section A and Section B (NE view).

Figure 7e: Photo of Reedy Creek (RCK) site - Section B and Section C (SW view).

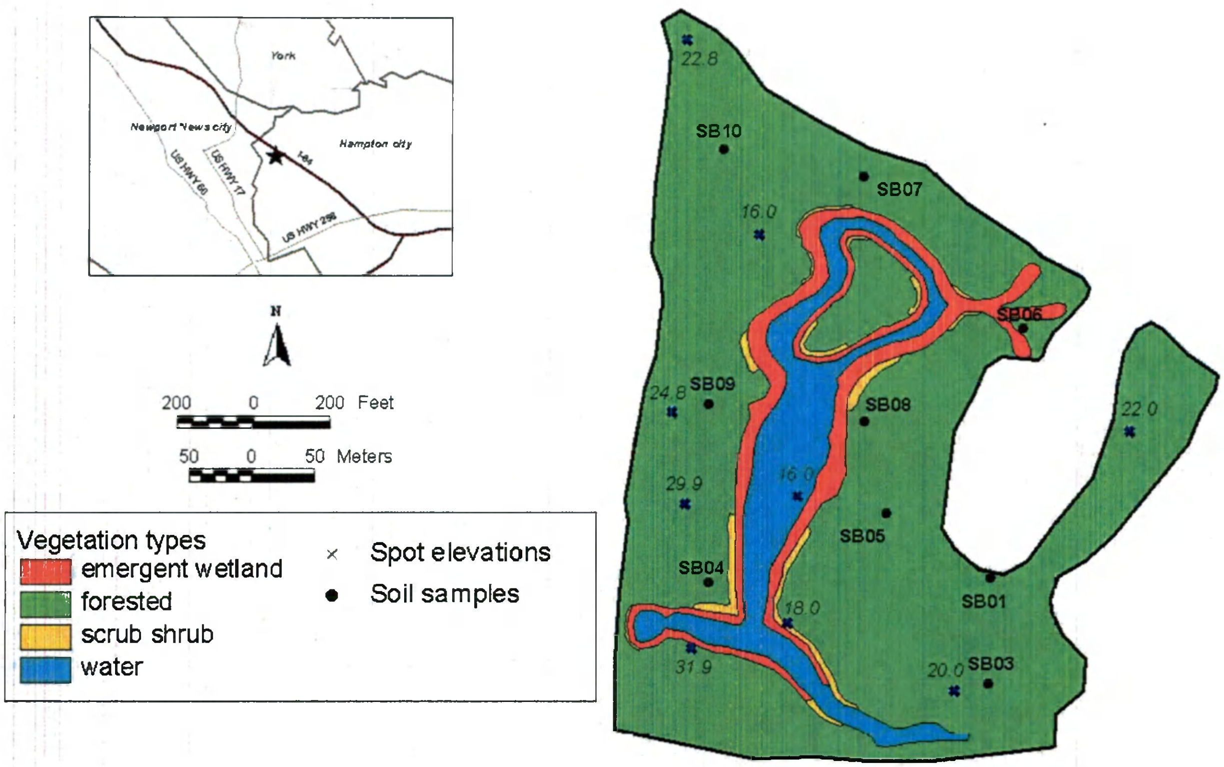

Figure 8a: Sandy Bottom (SB) site map (Fajardo 2006).

Figure 8b: Photo of Sandy Bottom (SB) site.

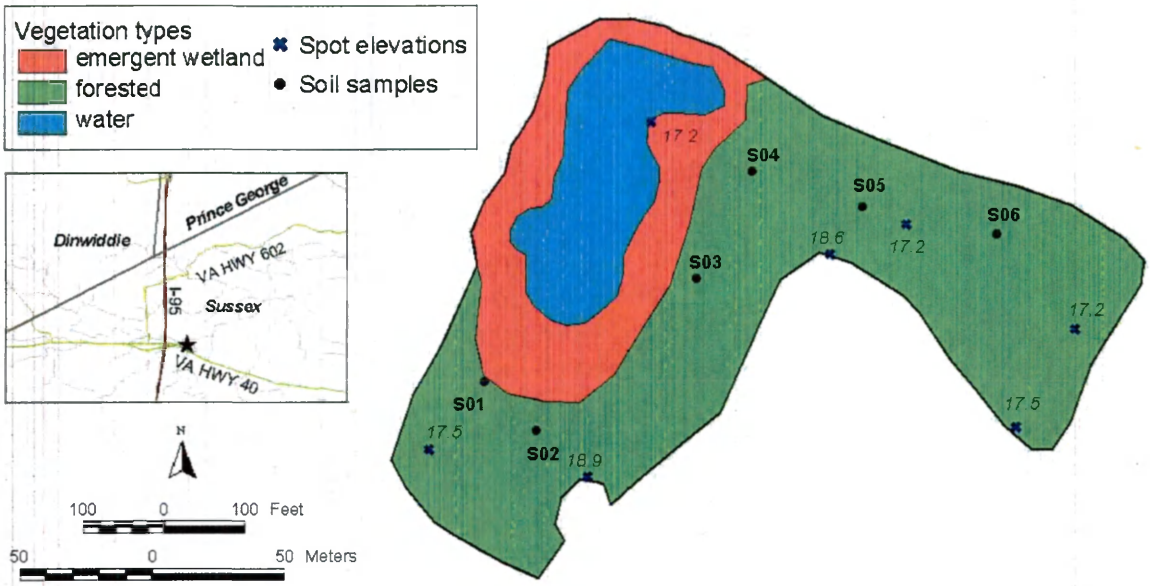

Figure 9a: Stony Creek (SCW) site map (Fajardo 2006).

Figure 9b: Photo of Stony Creek (SCW) site.

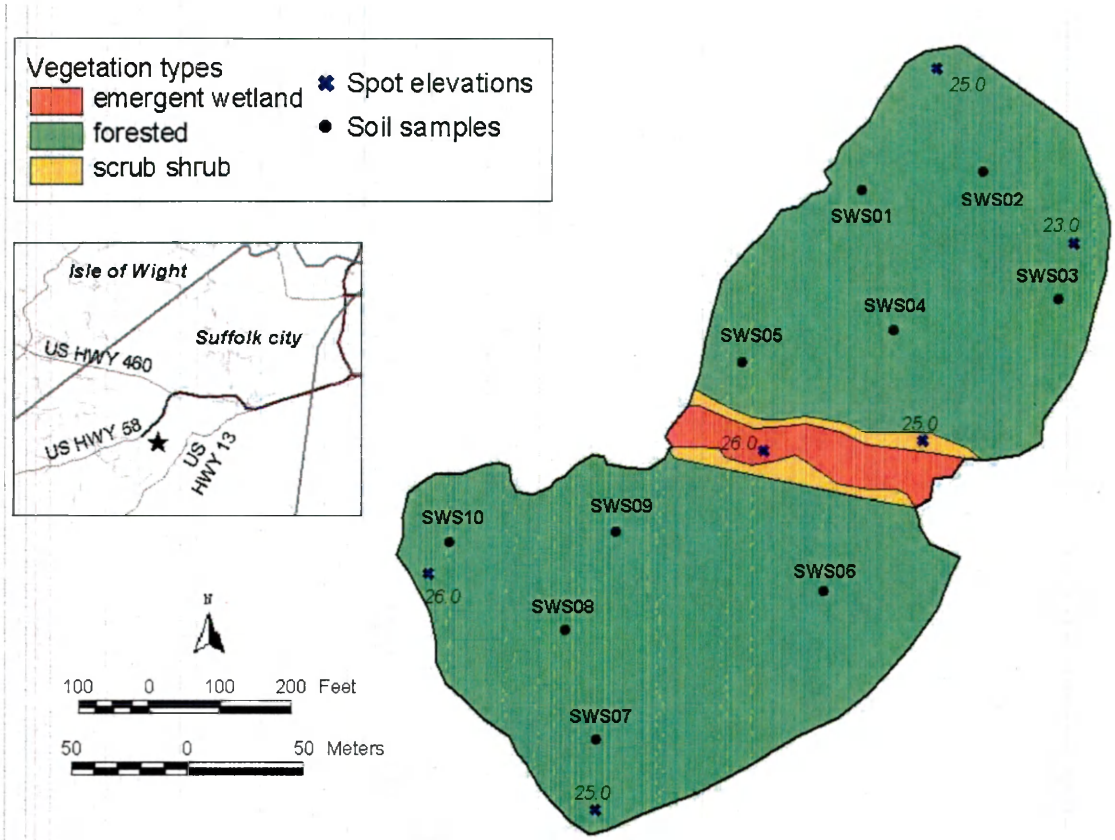

Figure 10a: SW Suffolk (SWS) site map (Fajardo 2006).

Figure 10b: Photo of SW Suffolk (SWS) site.

2.1.2 Field Sampling

2.1.2.1 Site Sampling Methodology

Sampling methods followed of Fajardo (2006). Michael J. Schmidt (Virginia Polytechnic Institute and State University) developed the methods and five sites in 2002 (CCW, DC, MAN, MATTA, and SCW). Fajardo (2006) subsequently sampled the remaining sites in 2003 (MTS, SB, and SWS) and 2004 (RCK and SWS).

Sample locations (plots) within each site were determined by stratified random sampling whereby an electronic grid was superimposed onto a digital image of the site map, and adjusted to create a number of sampling locales depending on the size of the wetland. The larger sites (> 4 ha) were each given ten (CCW, DC, MAN, MATTA, MTS, SB, and SWS) or fourteen (RCK) sampling locations. For the smaller wetland (< 4 ha: SCW), the sampling numbers were reduced to at least one sampling location per 0.5 ha. Plot locations were identified by designation of nodes within the borders of the created wetlands. Specifically, they were within the areas designated as forested locations. These nodes on the grid were equivalent to the number of sampling plots.

The plot sample locations from Fajardo (2006) were relocated using a Garmin GPSmap 76Cx (95% of errors are 4.4m or less, average error is 2.0m, and drift is 3m/min (Garmin)). Care was taken to be as close to the original sampling plot as possible. Out of the original 88 points, 86 were re-located. One plot location each from Reedy Creek (RCK3), and Manassas (MAN5), had to be excluded from the study because of their current location underwater.

Fajardo (2006) prepared a detailed soil description of the pedon at each plot, from a location deemed to be typical of the "surrounding 10m (based on vegetation, surface conditions and elevation). If the grid location was in standing water (> 10 cm), all samples except the composite surface samples were instead taken from closest non-ponded soil."

Vegetative sampling for this study took place in the same plots, but at a different time (June and September 2008), as soil sampling which took place in the Fall and Winter of 2008-2009.

2.1.2.2 Vegetation Sampling

In June 2008 all sampling plots that could be located were marked by multiple plastic tree shelters or nylon marking tape to insure that the same point was sampled throughout the season. Quadrats were used to visually estimate percent cover of plant species. Four 1m PVC pipes were used to form $1m^2$ quadrats around the designated GPS plots (Figure 11) and plant cover was estimated for each plant species (see text below for cover scale used). Other information included general weather conditions and whether woody vegetation greater than six feet tall cast a shadow on the plot.

Digital photographs were taken of every species encountered. In addition, detailed photographs were taken in the late summer of each cardinal view of the wetland, as seen from each of the plots. Photos were also taken in early summer for all sites except Charles City and Manassas.

Care was taken to collect at least two specimens of higher vascular plants as seen in plots; however, plants were not collected directly from the plots. Plants were identified in the field or laboratory to the lowest taxonomic level possible. Specimens are archived in the Herbarium at The College of William and Mary (Appendix 5.3).

2.1.2.3 Soil Sampling

Ten random, 2cm x 15cm deep soil cores were taken from within a 10m radius around each of the sampling plots. In Fajardo (2006), this was the surface core (0-15 cm). In this study, each core (0-15 cm) was sub-divided into four depth increments (0-2cm, 2-5cm, 5-10cm, 10-15cm) (Figures 12, 13). These depth increments were pooled into separate Ziploc® bags, creating four composite soil samples by depth (i.e. 0-2cm, etc) for each plot. Soil samples were stored in a refrigerator prior to analysis.

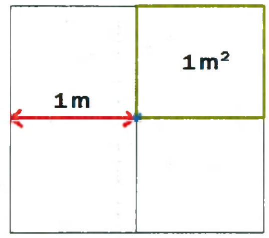

Figure 11: Quadrat layout utilized to visually analyze percent vegetative cover.

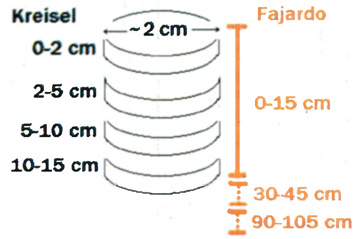

Figure 12: Comparison of soil core sampling methodology by study.

Figure 13: Cutting a soil core into four increments by depth (0-2 cm, 2-5 cm, 5-10 cm, 10-15 cm).

2.1.2.4. Hydrologic Evaluation

During each successive visit, sites were qualitatively analyzed for relative hydrologic conditions by recording qualitative soil moisture conditions (Table 5) and depth of any standing water on site. Depth of any standing water was measured to the nearest centimeter.

Table 5: Qualitative assessment criteria of average hydrology by site as assessed by relative soil moisture conditions.

Not Saturated	Soil appears to be completely dry.
Damp	Soil surface may have limited moisture present, but is not wet to the touch.
Saturated	Soil is noticeably wet at the surface but no standing water is present.
Saturated-Inundated	Individual sampling areas are represented by areas that are both saturated *and* inundated (due to microtopographic variation).
Inundated	Standing water is present in the entire sampling area, depth noted.

2.1.3 Laboratory and Analytical Methods

2.1.3.1 Vegetation

The percent cover values were imported to the modified Braun-Blanquet cover scale (Daubenmire 1959; DeBerry and Perry 2004; Bailey et al. 2007) to estimate percent cover for each plot, and each wetland as a whole. The percent cover in each quadrat was estimated in the field as a value from 1 to 100% or trace (<1%) (Table 6). These values were converted to the modified Braun-Blanquet cover scale (Daubenmire 1959; DeBerry and Perry 2004; Bailey et al. 2007).

Table 6: Modified Braun-Blanquet cover scale.

0.1%	3%	15%	37.5%	62.5%	85%	97.5%
Trace (<1%)	1%-5%	5%-25%	25%-50%	50%-75%	75%-95%	95%-100%

The sum of the species cover estimates may exceed 100% due to overlapping herbaceous leaf, and woody branch layers, even when the total cover was less than 100% (Daubenmire 1959; Moser et al. 2007).

Plants were identified in the field or lab to the lowest taxonomic level, using collected specimens when possible, and digital images when specimens were not available. Identification was performed with assistance of J.E. Perry and Doug DeBerry, using the vascular plant manual (Gleason and Cronquist 1995) and the illustrated companion (Holmgren 2005). Voucher specimens were pressed and are archived in the herbarium at The College of William and Mary (Appendix 5.3).

Wetland indicator status (WI), as assigned by the U.S Fish and Wildlife Service (Environmental Laboratory 1987; U.S. Fish and Wildlife http://www.fws.gov/wetlands, Tiner 2006) was used to determine whether the plots and sites were dominated by hydrophytic vegetation (Table 3). Using the USDA Plant Database, the wetland indicator status of each species can be identified (Table 7). For purposes of this study, I have also included an "unknown" indicator code category. This category was used to describe plants that were unidentifiable to species or higher levels, and as a result a wetland indicator status could not be determined.

Relative cover was calculated from the modified Braun-Blanquet values and relative frequency from a presence/absence conversion of the cover data (trace or greater was equal to present, and was represented by 1, whereas absent was represented by 0). From these two values, the relative importance value (IV) of each of the vegetative species in each of the sites was acquired (Bailey et al. 2007; Atkinson et al. 1993) and applied to determine the dominant species (Appendix 5.4).

Table 7: Wetland Indicator categories (USDA).

Indicator Code	Wetland Type	Comment
OBL	Obligate Wetland	Occurs almost always (estimated probability 99%) under natural conditions in wetlands.
FACW	Facultative Wetland	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
FAC	Facultative	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU	Facultative Upland	Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
UPL	Obligate Upland	Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List.
NI	No indicator	Insufficient information was available to determine an indicator status.
NO	No occurrence	The species does not occur in that region.
(+) or (-)		Used with the Facultative Indicator categories to more specifically define the regional frequency of occurrence in wetlands. The positive sign indicates that species is more frequently found in wetlands, and a negative sign indicates that species is less frequently found in wetlands.

Dominant species of each of the sampling plots that were calculated from the importance values (IV) were determined to be all plant species that together comprised > 50% of the total percent IV of each plot. This is the dominance threshold (Tiner 1999) and could be comprised of one or more species. Any species compromising 20% or more IV was considered dominant (Tiner 1999; Mitsch and Gosselink 2000).

Data from vegetative percent cover could not be directly compared to previously compiled data (Fajardo 2006). Instead, an evaluation of woody species presence or absence from sites, overall plots cover, as well as the relative hydrophytic status of site dominant species was used to track plant community development.

2.1.3.2 Soil

Soil hue, value, and chroma of the matrix (or matrices), as well as any redoximorphic (redox) features, were evaluated from the loose bag, moist soil samples using a Munsell soil chart (Munsell 2000). The contrast of the redox features from the matrix was recorded, as was the occurrence of larger roots or other macro-organic matter. Soil chroma from this study were compared against those from Fajardo (2006) using weighted averages across the four soil depths to compare soil oxidation status since the previous study.

Mineral hydric soils are determined by chroma colors at specified depth: immediately below the A-horizon or at ten inches (30 cm), whichever is shallower. Because this depth was not included in this study (soil samples to 15cm), samples could not be defined as hydric or otherwise. Instead, a weighted average value of the chroma in the more shallow soil layers to 15cm conveys the potential for these plots to have been hydric, had a full evaluation been conducted. In this respect evaluations were according to the Field Indicators of Hydric Soils in the United States (USDA 2003). For the current study, mineral hydric soils were evaluated using the Munsell Soil Chart (Munsell 2000) using two indicators of hydric soil: a matrix chroma of ≤ 2 in soils with depletions or concentrations; or a matrix chroma of ≤ 1 in soils without depletions or concentrations. The abbreviations used were according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002).

Using an open-barreled syringe, 5cc sub-samples were acquired from the bagged bulk soil sources, freeze-dried using a Labconco Freeze Dry System/ Freezone 4.5, and then ground with a mortar and pestle. From these samples, modified soil particle density (MSPD), and soil moisture were determined. Percent OM was acquired through weight loss on ignition. The final soil characteristics for 0-15cm for MSPD, and OM, resulted from a weighted average from the results of the four depth increments analyzed. These results were then compared against Fajardo (2006). Percent OM was not specifically analyzed in Fajardo 2006, so %C (Chapter 3) was extrapolated using an overestimating conversion factor of 0.58 (Nelson and Sommers 1982).

2.1.4 Developmental Trajectories

In producing this trajectory I am assuming a linear relationship over time among all of the sites in my study, and the younger and natural counterparts to the sites. Soil and vegetative characteristics from created sites, as reported in my study and Fajardo (2006), are compared against data from natural reference sites, as reported in DeBerry (2006).

2.1.5 Statistical Analysis

All comparisons of the measurement variables among studies, sites, and depths were analyzed using SPSS System for Windows, Version 17.0 (2008), setting the level of statistical significance at $p \leq 0.05$.

For data that were non-normally distributed, statistical comparisons between variables were evaluated using the PASW System for Windows, Version 17.0.2 (2009). The Wilcoxon Rank Sum Test was used to compare all variables examined in this study between sites (e.g., comparing % OM data among all sites in this study). The Wilcoxon Signed Rank Test was used to compare variables between studies (e.g., comparing % OM data at CCW of this study, to the data from Fajardo (2006)), and to compare single variables within a plot at different depths (e.g., comparing % OM data at CCW1 between 0-2cm and 2-5cm). In this manner, covariance effects are removed from the test. Both nonparametric tests are based on the assumption that data arise from randomly selected pairs that are matched up (Motulsky 1995). Neither assumes normal distribution but both allow for smaller sample sizes than their t-test counterpart (the two-sample, and paired t-tests, respectively).

Sørensen's Similarity Index was utilized to determine the similarity of species richness and woody species richness between this study and Fajardo (2006). The Paired T-test was also utilized to determine any statistical relationships between the studies (e.g., dominant vegetation, dominant hydrophytic vegetation, and hydrophytic plots). Pearson correlation was utilized to determine whether any significant differences existed among any of the site soil parameters. Principal components analysis (PCA) was used to examine relationships among multiple soil variables.

2.2. *RESULTS*

2.2.1 Site Vegetation

Fajardo (2006) collected a total of 54 higher vascular plant species, while I collected 162 species in this study. From both studies, a total of 191 species were encountered within plots at the study area (Table 8). Most of the flora in this study was identified in June 2008, with the additional identification of approximately 30 more species in September 2008 (Appendix 5.3).

Of the species that were successfully identified in the current study, only approximately 20% (29) were upland (UPL) or facultative upland (FACU). However, in the early growing season, FACU plants constituted a dominant portion of 67% (6) of the sites (Figure 14a), but this diminished to only 22% (2) of sites by the end of the growing season (Figure 14b). UPL plants were only dominant in two sites (SB, RCK) but this dominance both persisted and increased relative to other dominant species at the sites throughout the entire growing season.

The majority of the dominant plants, identified from importance values (IV), were obligate (OBL) or facultative wetland (FACW) (Figure 14). OBL plants were dominant throughout each site in the early summer, but decreased to about 40% of the sites by late summer (Figure 14). Even though most sites had more visible standing water in the latter half of the summer (Figure 20), fewer OBL species made up the vegetative community in September. Plants designated as FACW were dominant at every site throughout the growing season, and their relative dominance at all sites increased over time except at SB (decrease) and SCW (no change).

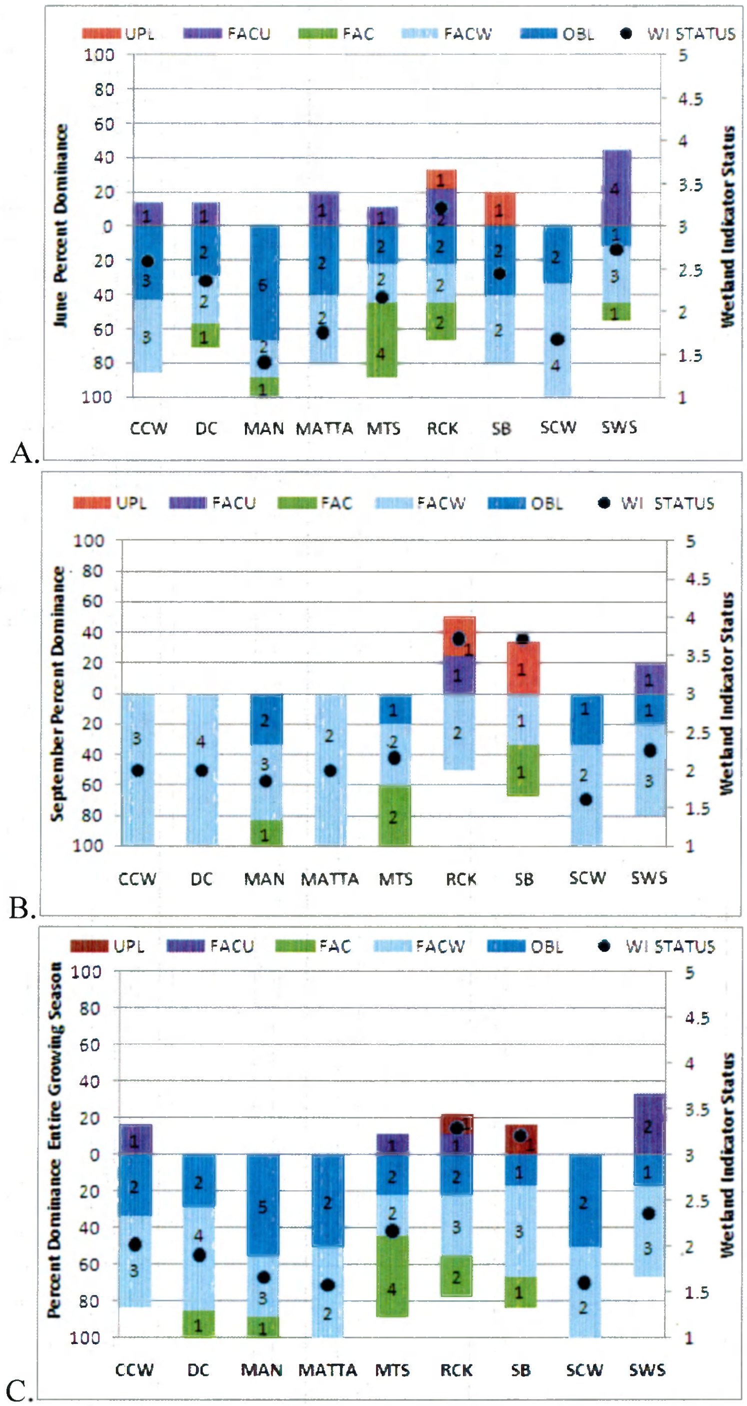

Figure 14: Dominant Vegetative Species by Wetland Indicator Status (WI) and Site. Early Growing Season (A.), Late Growing Season (B.), Entire Growing Season (C.) OBL (Obligate Wetland), FACW (Facultative Wetland) and FAC (Facultative) are all designations for hydrophytic vegetation. Relative dominance is displayed below 0%. UPL (Obligate Upland) and FACU (Facultative Upland) represent non-wetland species. Relative dominance is displayed above 0%. Each designation corresponds to a WI value (OBL, 1; FACW, 2; FAC, 3; FACW, 4; UPL, 5). Points indicate the average WI for that site. Bar values indicate number of vegetative species per WI per plot.

2.2.1.1 Vegetative Plot Cover

In this study, the sites exhibited an increase in vegetative plot cover from Fajardo (2006) (Figure 15). In Fajardo, DC contained the lowest overall percent vegetative cover (43.1%), while SB had the highest cover (102%). The average percent cover in 2006 study was 66.1% while the average in this study was 109.6%. Most sites experienced nearly 50% increases in overall plot cover, with the exception of SB which declined nearly 23%

Dick cross exhibited the greatest variation (56.5% (DC6) to 179.8% (DC5)) (Figure 16), and the least amount of variation was seen at Reedy Creek (90.6% (RCK6) to 130.1% (RCK1)). DC5 had the highest percent cover of the entire study (179.8%) and MATTA7 had the lowest percent cover of the study (47.7%).

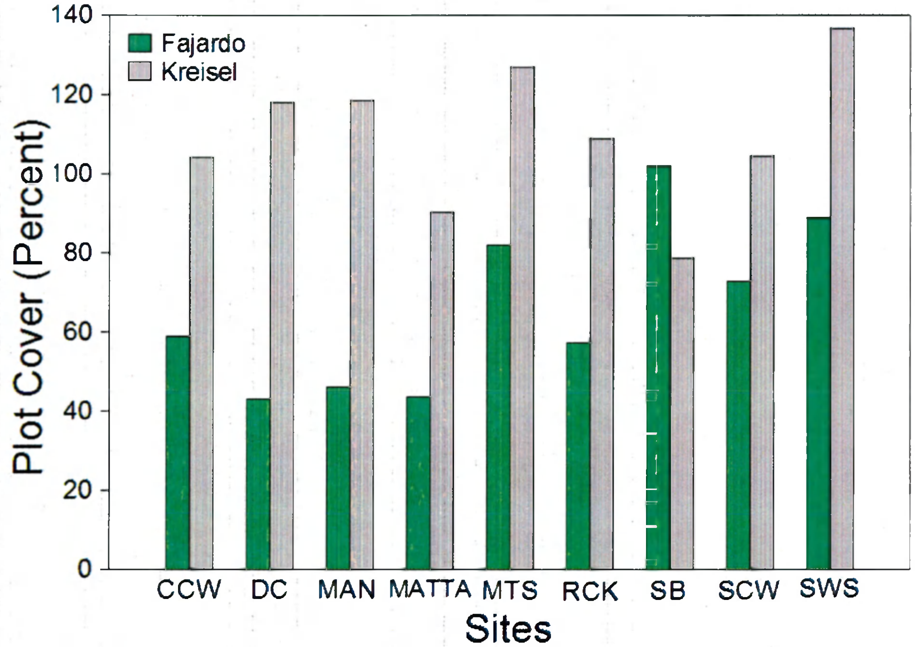

Figure 15: Total Average Plot Vegetative Cover at Sites for Both Fajardo (2006) and the Current Study.

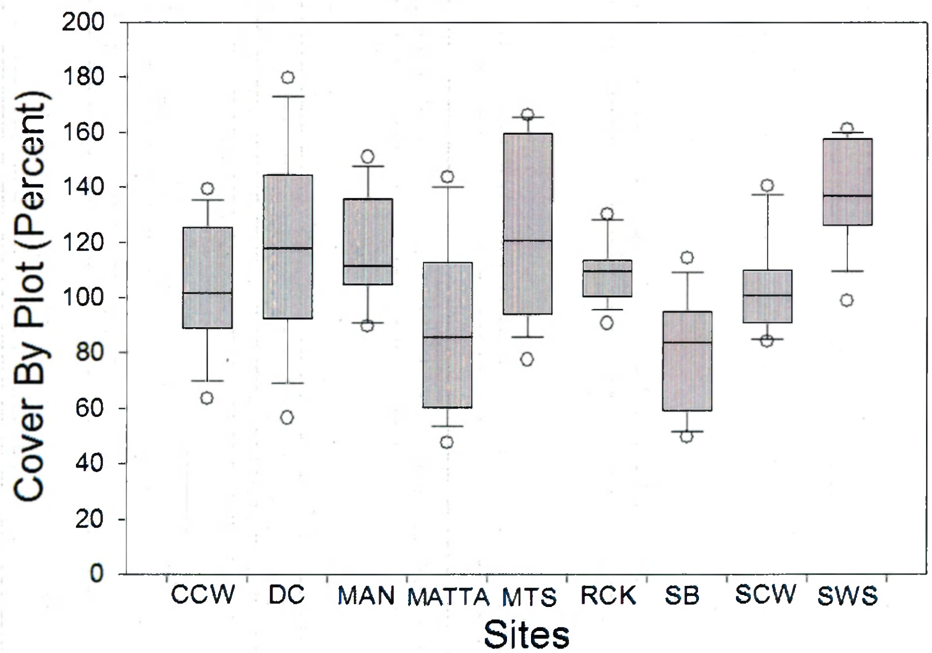

Figure 16: Individual Plot Vegetative Cover at Sites. Due to overlapping vegetative layers, cover estimates could exceed 100%, even when total cover was less than 100% (Daubenmire 1959).

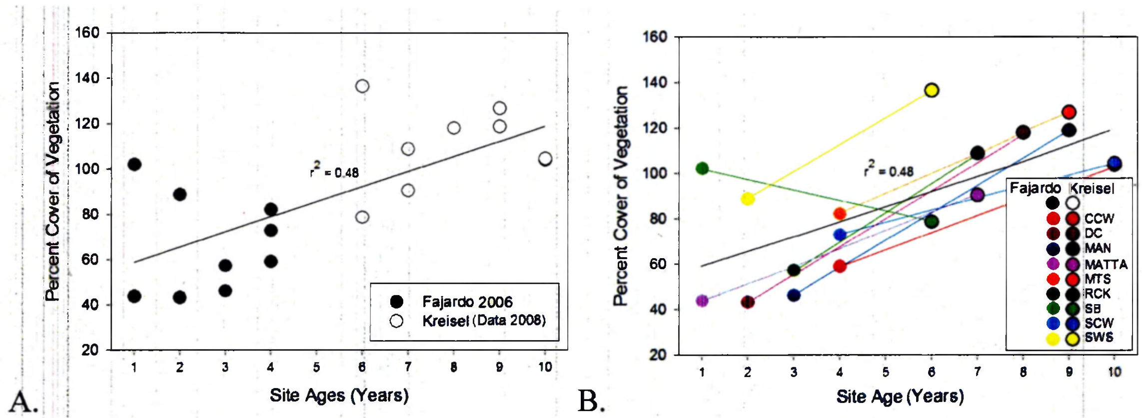

Figure 17: Percent cover of vegetation by site and study, comparison with Fajardo (2006). A) Regression (Trajectory). B) Developmental path established by each site in this study.

2.2.1.2 Hydrophytic Vegetation

Overall, I found a significant increase in species richness between Fajardo (2006) and this study (Table 8, Figure 18) ($p < 0.031$). Species richness at reference wetlands was lower than that of the created sites. Of the plant species encountered in Fajardo (2006), 54% (29) of these were not found during this study. Correspondingly, only 15% (25) of the species encountered in this study had been previously noted (Table 8). Overall, there exists a 0.46 similarity (SI) between studies (Table 8) indicating a weak similarity between studies.

The number of plants that made up the list of dominants did not change significantly between studies (Table 9) ($p < 0.710$, Paired T-Test). There were a total of 57 dominant species at all sites in Fajardo (2006) and 60 in the current study. There was no significant difference in the number of dominant hydrophytic vegetative species between studies over time ($p < 0.964$, Paired T-Test), but every site experienced an increase in percent dominant hydrophytic vegetative species. A majority of sites (5/9) exhibited a change in the total number of dominant species over time with increases observed at MATTA, MTS, and SCW, and decreases at RCK and SB.

Sites at which the number of dominant plants increased also had a concurrent increase in the number of hydrophytic dominant plants (MATTA, MTS, and SCW). The concurrent increase in dominant non-wetland plants at MTS, led to an overall decrease in the hydrophytic wetland plant value, even though MTS acquired more dominant hydrophytic species as well (3/3 (100%) hydrophytic in Fajardo, 8/9 (88.9%) hydrophytic in this study) (Table 9).

Table 8: Number of Encountered Vegetative Species by Study.

Study	# Species	# Unique to Study
Fajardo 2006	54	29
Kreisel (this study)	162	137
Total	**191**	**166**
Sørenson Similarity Index: 0.46		

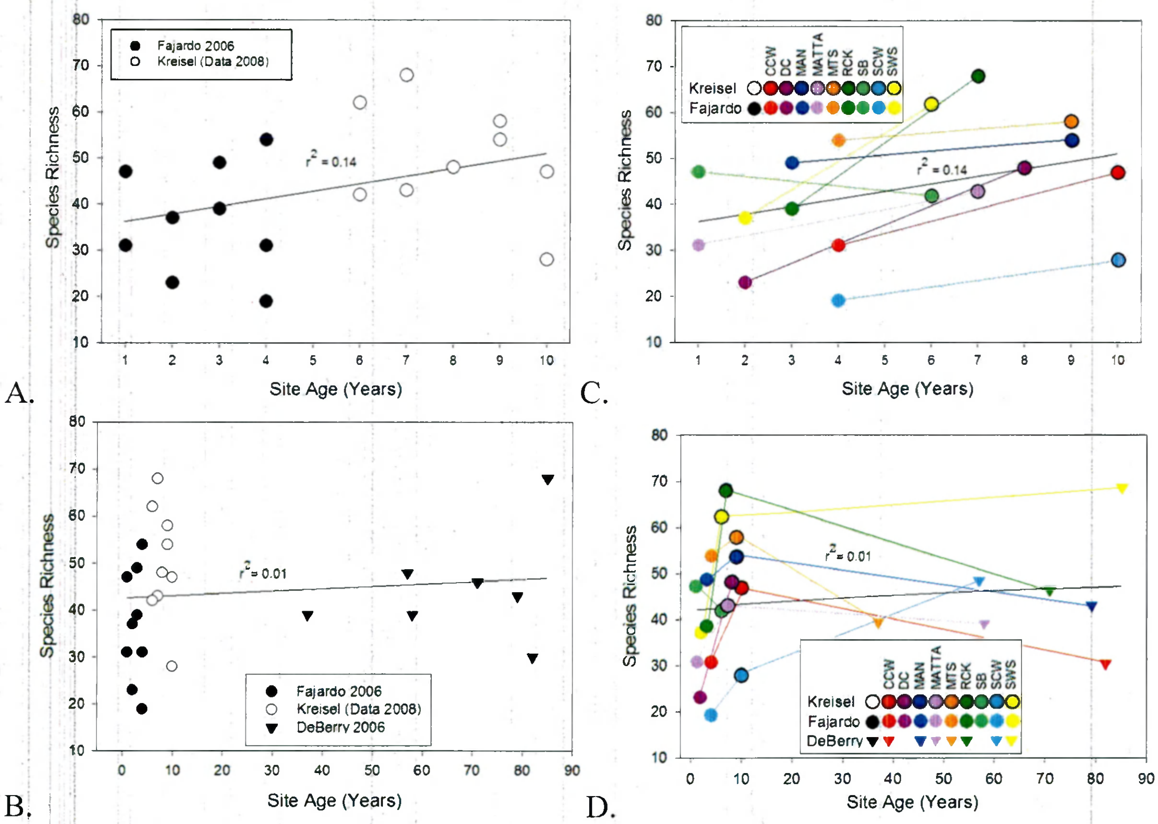

Figure 18: Species richness by site and study, comparison with Fajardo 2006, and DeBerry 2006 (reference sites). A) and B) Regression (trajectory) of created developmental growth. C) and D) Developmental path established by each site in this study.

MATTA and SCW both had respective increases in hydrophytic species, and as a result, these sites were dominated by hydrophytic vegetation (100% (3/3 in Fajardo, and 4/4 in this study for both sites)) in both studies. RCK also maintained 100% dominance by hydrophytic vegetation over time (9/9 species). Two sites (DC, MAN) increased the percent dominance by hydrophytic vegetation over time to 100% (7/7, and 9/9 species, respectively) (Table 9).

Even though RCK maintained 100% hydrophytic dominance, RCK, like SB, displayed a decline in the number of dominant, and dominant hydrophytic species during this study (10/10 (100%) hydrophytic in Fajardo, 9/9 (100.0%) hydrophytic in this study for RCK, 6/10 (60%) hydrophytic in Fajardo, 5/6 (83.3%) hydrophytic in this study for SB). As a result of the decrease, SB was characterized by second lowest % dominance of wetland plants of all of the sites in this study (83.3%, SB) (Table 9).

Comparatively, four of the sites (CCW, DC, MAN and SWS) all retained the same total number of dominant species over time (6, 7, 9, and 6, respectively). Each of these sites experienced an increase in hydrophytic species dominance (5/6 (83.3%), 7/7 (100.0%), 9/9 (100.0%), and 4/6 (66.7%), respectively). The mean number of dominant hydrophytic species remained well above the majority in most sites, for both studies 45/57 (78.9%) for Fajardo 2006, 55/60 (91.7%) for the current study (Table 9).

Table 9: Hydrophytic Dominant Vegetative Species Based on Wetland Indicator Status of Dominant Vegetation for Nine VDOT Sites in Eastern Virginia from Two Studies. Statistical difference between studies ($p \leq 0.917$).

	FAJARDO 2006 (sampling 2002 to 2004)		KREISEL (sampling 2008)	
	# Dom Species	# Hydric (% Hydric)	# Dom Species	# Hydric (% Hydric)
CCW	6	4 (66.7)	6	5 (83.3)
DC	7	5 (71.4)	7	7 (100.0)
MAN	9	8 (88.9)	9	9 (100.0)
MATTA	3	3 (100.0)	4	4 (100.0)
MTS	3	3 (100.0)	9	8 (88.9)
RCK	10	10 (100.0)	9	9 (100.0)
SB	10	6 (60.0)	6	5 (83.3)
SCW	3	3 (100.0)	4	4 (100.0)
SWS	6	3 (50.0)	6	4 (66.7)
TOTAL	**57**	**45 (78.9)**	**60**	**55 (91.7)**

Table 10: Number of Hydrophytic Plots Based on Dominant Vegetation (WI) for Nine VDOT Sites in Eastern Virginia from Two Studies. Statistical difference between studies $p \leq 0.068$.

ND = Overall these sites supported hydrophytic vegetation; however no data was available on individual plots.

^ = management occurred on vegetation at the site prior to sampling.

* = 4 plots are unaccounted for due to <2% vegetative cover. As a result, no conclusion could be made regarding hydrophytic status of those plots.

+ = 8 plots are unaccounted for. Four of these plots had little to no vegetative cover, and another four plots had dominance by both wetland and non-wetland type species. As a result, no conclusion could be made regarding hydrophytic status of those plots.

	FAJARDO 2006 (sampling 2002-2004)		This Study (sampling 2008)	
	# OF HYDROPHYTIC PLOTS (% WHOLE SITE)	# OF NON-HYDROPHYTIC PLOTS (% WHOLE SITE)	# OF HYDROPHYTIC PLOTS (% WHOLE SITE)	# OF NON-HYDROPHYTIC PLOTS (% WHOLE SITE)
CCW	5*(83.3)	1* (16.7)	8 (80.0)	2 (20.0)
DC	9 (100.0)	0 (0.0)	8 (88.9)	1 (11.1)
MAN	10 (100.0)	0 (0.0)	9 (100.0)	0 (0.0)
MATTA	10 (100.0)	0(0.0)	10 (100.0)	0 (0.0)
MTS	10 (100.0)	0 (0.0)	7 (70.0)	3 (30.0)
RCK	14 (100.0)	0 (0.0)	5 (38.5)	8 (61.5)
SB	1+ (11.1%)	ND	4 (44.4)^	5 (55.6)^
SCW	6 (100.0)	0 (0.0)	6 (100.0)	0 (0.0)
SWS	ND	ND	7 (70.0)	3 (30.0)
TOTAL	**65 (98.5)**	**1 (1.5)**	**64 (74.4)**	**22 (25.6)**

Of the individual plots evaluated in the Fajardo (2006) study, 65/66 (98.5%) were deemed hydrophytic (Table 10). Six of the sites (DC, MAN, MATTA, MTS, RCK, and SCW) in the 2006 study were 100% dominated by hydrophytic vegetation. Of the remaining sites, no data were available for two (SB, SWS), and the last site (CCW) could not fully be accounted for due to a lack of present vegetation, and one plot at CCW was dominated by upland plants (CCW9).

Some plots evaluated in Fajardo (2006) were found to no longer be dominated by hydrophytic vegetation (12/66 (18%)). Additional plots not previously identified in Fajardo (CCW, SB, SWS) were found to be dominated by non-hydrophytic vegetation (10/86 (12% of plots evaluated in this study)). Still, I found no statistical difference ($p < 0.818$, Paired T-test) between the plots that exhibited this change between studies. Even so, a majority of the plots in this study were still dominated by hydrophytic vegetation (64/86 (74.4%) (Table 10). A majority of the sites (CCW, DC, MAN, MATTA, MTS, SCW, and SWS) shared this characteristic. A third of the sites were dominated entirely by hydrophytes (MAN, MATTA, and SCW). Correspondingly, these were some of the wettest sites in the study. Two sites, RCK and SB had a majority of plots (61.5% and 55.6%, respectively) dominated by non-hydrophytic vegetation. The remaining four sites (CCW, DC, MTS, and SWS) had between 70.0% to 88.9% hydrophytic dominated plots.

2.2.1.3 Woody Vegetation

The presence of woody vegetation tended to increase between studies (Table 11) ($p < 0.299$). Twenty-one woody species were encountered in Fajardo (2006) and twenty-six in this study. Woody vegetation was present in every site at all times during both studies; however the composition of species varied (Table 11, 12, 13). On average I found a total of 7.5 woody species / site versus 5.5 woody species / site in Fajardo.

There was a considerable range in the number of woody species that were present at each of the individual sites from 2 (SB) to 14 (RCK) species per site (Table 12, Figure 19, Appendix 5.5). There was an overall change in the number and composition of the woody community at every site, and a majority of sites (CCW, DC, RCK, SCW, SWS) displayed an overall increase in woody species richness (Table 12). Overall, there was a moderate level of similarity of woody species between the studies (average of 0.62), although similarity ranged from 0 (SB) to 0.92 (SCW) (Table 12).

Three sites exhibited a decrease in woody species richness (MATTA, MTS, SB), while one site (MAN) had no change. Many of the species that were planted and/or were present during the Fajardo (2006) were missing in seven out of nine sites, but there was also an influx of new volunteer species into these sites as well (Table 13). The remaining two sites (DC, RCK) were characterized by a single woody species during the Fajardo study (*Salix nigra, Acer rubrum*, respectively). These two species persisted at these sites, and the sites were characterized by volunteer species in this study as well. SB was the only site to not have any of its six species maintained between studies.

Table 11: Number of Encountered Woody /Shrubby Species in Two Studies

Study	# Species Woody/Shrubby (Total)	# Unique to Study Woody/Shrubby (Total)
Fajardo 2006	19/2 (21)	8/1 (9)
Kreisel (Current Study)	20/6 (26)	9/5 (14)
Total	**38/9 (47)**	**17/6 (23)**

Table 12: Number of Encountered Woody /Shrubby Species over Two Studies by Site (Fajardo 2006, and current study (data from 2008).
PairedT-test between studies $p < 0.299$.
*= Sørensen's Similarity Index

Study	# Woody Species		Difference	# Unique to Study		Index of Similarity*
	2006	2008		2006	2008	
CCW	3	7	+4	1	5	0.80
DC	1	6	+5	0	5	0.57
MAN	6	6	0	4	4	0.67
MATTA	8	3	-5	7	2	0.36
MTS	14	10	-4	9	5	0.83
RCK	1	14	+13	0	13	0.27
SB	6	2	-4	6	2	0.00
SCW	5	8	+3	2	5	0.92
SWS	6	12	+6	2	8	0.89
TOTAL	**50**	**68**	**+18**	**31**	**49**	**0.62**

Table 13: Summary of All Woody and Shrubby Species Encountered in Plots by Study. Bold indicates a species that's common to both studies at that site.
^ = Species not encountered in the 2006 study because planting occurred after sampling.

	2006	*2008*
CCW	***Acer rubrum, Liquidambar styraciflua,*** *Taxodium distichum*	***Acer rubrum****, Albizia julibrissin, Betula nigra^,* ***Liquidambar styraciflua,*** *Pinus taeda, Quercus laurifolia, Rubus allegheniensis*
DC	***Salix nigra***	*Ilex verticillata, Pinus taeda, Quercus Phellos^, Rubus allegheniensis,* ***Salix nigra****, Spiraea tomentosa*
MAN	***Acer negundo, Cephalanthus occidentalis,*** *Fraxinus pennsylvanica, Quercus coccinea, Symplocos tinctoria, Taxodium distichum*	***Acer negundo, Cephalanthus occidentalis,*** *Quercus palustris, Quercus Phellos, Rosa palustris, Rubus allegheniensis*
MATTA	***Acer rubrum****, Carya carolinae, Cephalanthus occidentalis, Fraxinus pennsylvanica, Quercus michauxii, Quercus Phellos, Salix nigra, Ulmus americana*	***Acer rubrum****, Liquidambar styraciflua, Quercus bicolor*
MTS	***Acer rubrum****, Alnus serrulata, Fraxinus pennsylvanica,* ***Liquidambar styraciflua, Pinus taeda,*** *Platanus occidentalis, Quercus lyrata, Quercus michauxii, Quercus pagoda,* ***Quercus palustris,*** *Quercus Phellos, Salix nigra,* ***Taxodium distichum,*** *Ulmus americana*	***Acer rubrum****, Betula nigra^, Cornus florida,* ***Liquidambar styraciflua, Pinus taeda, Quercus palustris,*** *Rubus allegheniensis,* ***Taxodium distichum****, Ulmus rubra, Viburnum dentatum*
RCK	***Acer rubrum***	***Acer rubrum****, Betula nigra, Cephalanthus occidentalis^, Cornus florida, Fraxinus pennsylvanica, Liquidambar styraciflua, Nyssa sylvatica, Pinus taeda, Platanus occidentalis, Quercus laurifolia, Quercus palustris, Rubus allegheniensis, Salix nigra^, Spiraea tomentosa*
SB	*Betula nigra, Fraxinus pennsylvanica, Liquidambar styraciflua, Platanus occidentalis, Quercus lyrata, Ulmus americana*	*Quercus palustris, Salix nigra*

Table 13 continued

SCW	*Betula nigra, **Fraxinus pennsylvanica,** Quercus pagoda, **Salix nigra, Taxodium distichum***	*Acer rubrum, **Fraxinus pennsylvanica,** Liquidambar styraciflua, Quercus palustris, **Salix nigra,** Spiraea tomentosa, **Taxodium distichum,** Ulmus rubra*
SWS	***Acer rubrum, Cephalanthus occidentalis,** Pinus serotina, **Pinus taeda,** Quercus pagoda, **Taxodium distichum***	***Acer rubrum,** Albizia julibrissin, Baccharis halimifolia, **Cephalanthus occidentalis,** Diospyros virginiana, Ilex opaca, Liquidambar styraciflua, **Pinus taeda,** Rosa palustris, Rubus allegheniensis, Salix nigra, **Taxodium distichum***

Table 14: All Woody and Shrubby Species Encountered in Plots, and Common to Both the 2006 and 2008 Studies.
^ = Species not encountered in the 2006 study because planting occurred after sampling.
* = Site that was sampled before planting, so species not encountered in 2006 study.

SPECIES	SITE
Acer negundo	MAN
Acer rubrum	CCW, MATTA, MTS, RCK, SWS
Betula nigra^	CCW*, MTS*
Cephalanthus occidentalis	MAN, RCK*, SWS
Fraxinus pennsylvanica	SCW
Liquidambar styraciflua	CCW, MTS
Pinus taeda	MTS, SWS
Quercus palustris	MTS
Quercus phellos^	DC*
Salix nigra	DC, RCK*, SCW
Taxodium distichum	MTS, SCW, SWS

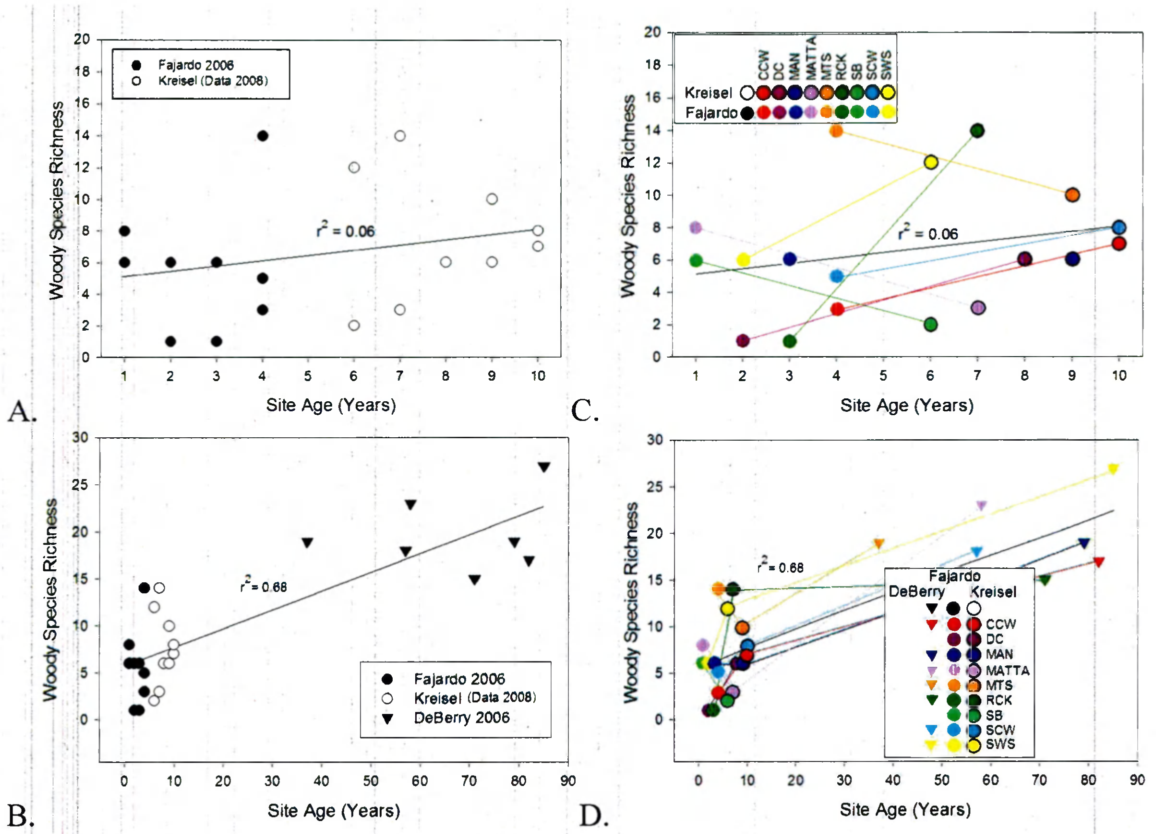

Figure 19: Woody species richness by site and study, comparison with Fajardo 2006, and DeBerry 2006 (reference sites). A) and B) Regression (trajectory) of created developmental growth. C) and D) Developmental path established by each site in this study.

Few species were common to both studies (Table 12, 13, 14). Throughout the studies, between zero and four species persisted within individual sites; and eleven species persisted between studies (Table 12). *Acer rubrum* was by far the most successful species since it persisted throughout five of the sites (Table 14), and was also novel in another (Table 13). Mt. Stirling contained the highest number of persistent woody species (six) between studies.

Six of the sites were planted with woody species after vegetative sampling took place in Fajardo (2006) (Table 4). In most cases this did not affect the outcome of these data, since only two species persisted (*Betula nigra, Quercus phellos*) (Table 14).

Many of the woody species common to both studies carried WI status of facultative, rather than a more definitive wetland designation (5/11) (Table 14). Of the woody species that were new for this study, 9/13 were wetland plants (1 OBL, 6 FACW, 2 FAC) whereas the other four were non-wetland species (3 FACU, 1 UPL) (Table 13). SB was the only site not to have any woody species remain from the previous study.

2.2.2 Hydrology

Qualitatively, a majority of the sites were saturated[1] for the duration of the field season (Table 15, Figure 20). DC and MTS were between damp and saturated for the field season. The exceptions to this were SB and RCK which were not saturated for the field season. In addition to being saturated, much of CCW and SCW were also characterized by inundation.

On average during the growing season, CCW, MAN, MATTA, and SCW were under saturated conditions (Figure 20). SB and RCK had nearly completely unsaturated conditions. Conditions at DC, MTS, and SWS were closer to damp.

[1] In this study, "saturated" refers to saturated to the surface

Table 15: Qualitative assessment of average hydrologic levels by site as assessed by relative soil moisture conditions during the 2008 field season. Presence of the letter represent the strong presence of that water level during the indicated sampling period.

	Not Saturated	Damp	Saturated	Saturated-Inundated	Inundated	
CCW	J		J	SW	SW	
DC	J	S	SW		SW	
MAN			JSW	W	S	June
MATTA	S		JSW	W	JW	September
MTS	JSW	S	JS	W	W	Winter
RCK	JSW	JS	W	W		
SB	JS	SW	W			
SCW	J				SW	
SWS	JW		JSW	SW	W	

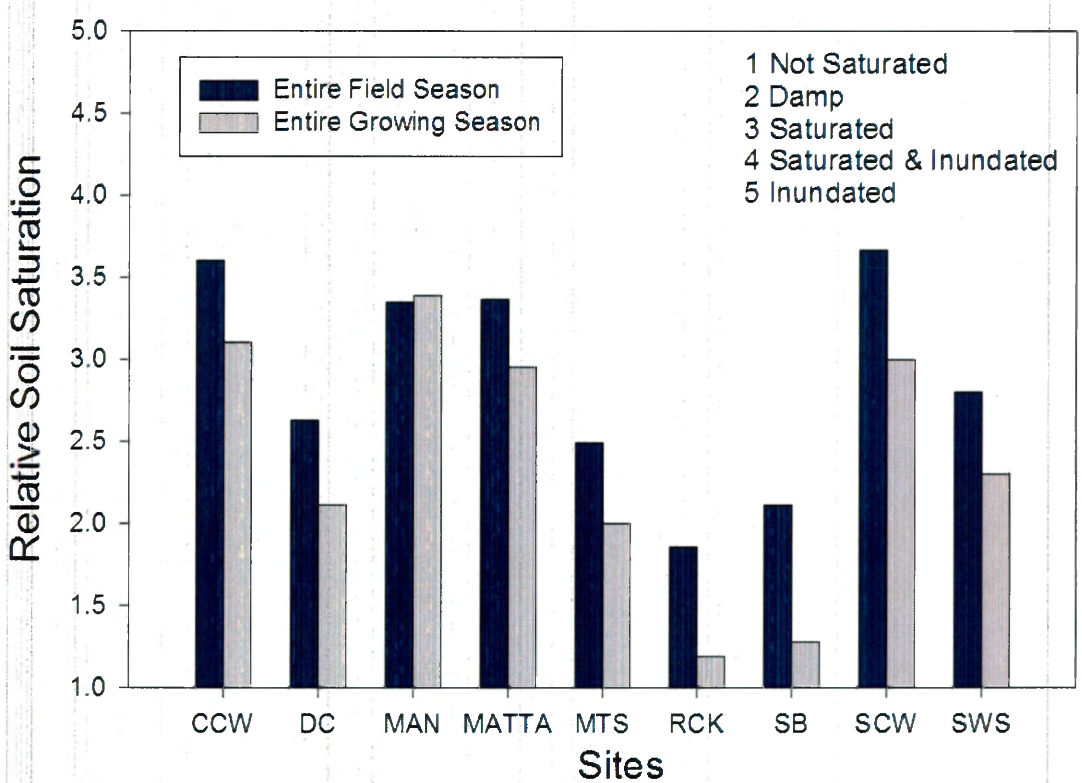

Figure 20: Relative Soil Saturation by Site. Entire Growing Season includes June 2008 and September 2008 sampling. Entire Field Season includes the growing season and soil sampling in November (SB), January (all sites except SB) and February (SWS). Relative soil saturation value 1 < 2 averaged between not saturated and damp; 2 < 3 averaged between damp and saturated; 3 < 4 averaged between saturated and inundated & saturated; 4 < 5 averaged between saturated & inundated and inundated.

2.2.3 Physical Soil Properties

2.2.3.1 Modified Soil Particle Density (MSPD)

In the Fajardo study, MSPD ranged from 1.35 g/cc (RCK) to 1.82g/cc (SB). At that time, these sites had significantly lower and higher MSPD, respectively, relative to the other sites (Figure 21b). Data from this study show that MSPD has significantly decreased, as a study, since Fajardo (2006), ranging from 1.24g/cc (± 0.02 SE) (CCW) to 1.57g/cc (± 0.02 SE (SB) ($p \leq 0.008$) (Figure 21b, Appendix 5.7), but the average MSPD among sites within this study were not statistically significant (Appendix 5.8.1).

MSPD was consistently greater with depth at every site in this study (Figure 21a). The greatest difference in depth occurred between the two most shallow soil layers (0-2cm and 2-5cm), ranging from an average of 0.12g/cc (SCW[2]) to 0.51g/cc ± 0.068 SE (MAN). MSPD was higher through both the 5-10cm, and 10-15cm layers in all sites. However, the increase was less drastic than the change in the surface layers, ranging from -0.02g/cc (SCW) to 0.10g/cc (MTS). Significant differences in MSPD existed between all layers in all sites, except that the 5-10cm layer was only significantly less dense than the 10-15cm layer at CCW, MTS, and RCK (Appendix 5.7).

In this study, the 0-2cm layer MSPD ranged from 0.72g/cc (± 0.03 SE) (MAN) to 1.35g/cc (SCW*). SB contained the second highest surface MSPD at 1.26g/cc (± 0.03 SE). For the deepest soil layer sampled, 10-15cm, samples were characterized by MSPDs ranging from 1.4g/cc (± 0.02 SE) (CCW) to 1.65g/cc (± 0.02 SE) (SB) (Figure 21a, Appendix 5.7).

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[2] SCW could not be fully accounted for, due to a partial data set.
Hereafter, SCW* refers to having used a partial data set in the study.

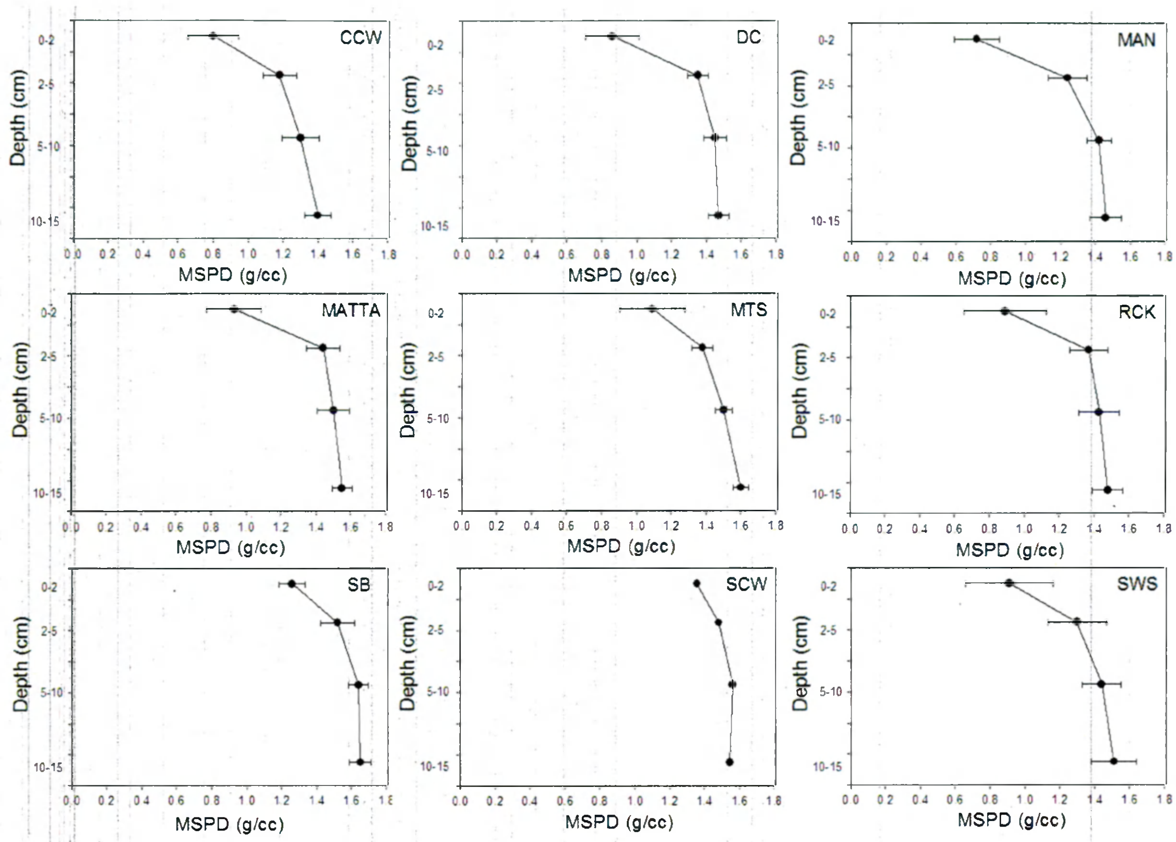

Figure 21a: Modified Soil Particle Density (MSPD) for all sites by depth from the surface.

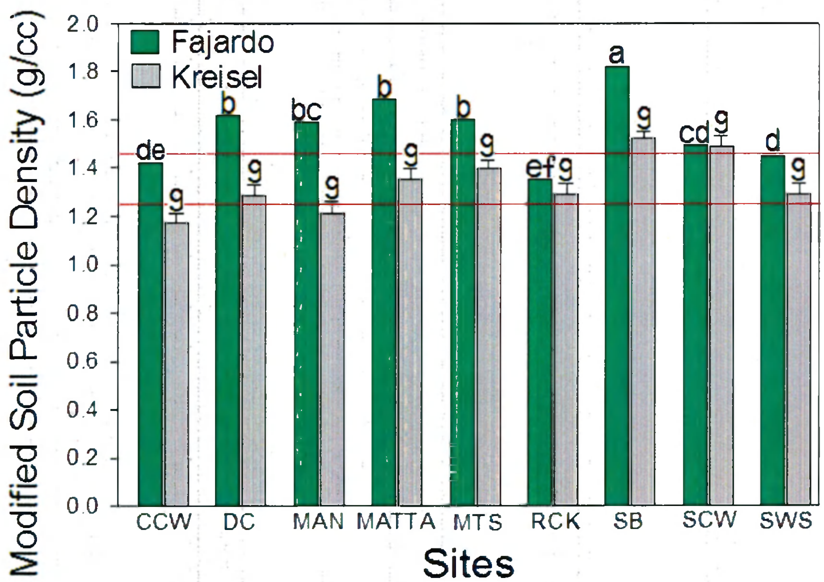

Figure 21b: Mean modified soil particle density (MSPD) + SE by study and site from 0-15cm. Different letters (i.e. a, b) between bars indicate a significant difference within this study ($p < 0.05$). Significant differences existed between sites within Fajardo 2006 (i.e. a - f), within the current study (i.e. g) and between studies ($p < 0.021$). 1.25g/cc is the MSPD of a typical mineral soil (Brady and Weil 2008), while 1.45g/cc is the low root-limiting threshold (Daniels and Whittecar 2004).

2.2.3.2 Organic Matter (OM)

Overall, OM increased significantly from the last study ($p \leq 0.011$), most sites having doubled the average amount of OM in the soil. Fajardo (2006) found that the average OM in the 0-15 cm layer for all sites was 2.46% (± 0.11 SE). This study shows that sites now contain 4.02% (± 0.16 SE) OM in the top 15cm of the soil (Figure 22b). I found no statistical difference in soil OM among any of the sites in this study. In the reference sites, soil OM ranged from 4.5% (MTS) to 20.6% (CCW) (Figure 23).

At the time of the previous study, only two of the sites (SCW, SWS) had > 4% OM. In the current study, however, seven sites (CCW, DC, MAN, RCK, SB, SCW, and SWS) acquired >4% OM. Two sites (MATTA and MTS), while showing an increase in OM over time, still have not achieved that 4% level.

Organic matter decreased with depth at each of the plots and sites (Figure 22a). The surface (0-2cm) layer was 7.88% (±0.91 SE) on average, and contained significantly more OM than each of the deeper layers in every site, with the exception that MTS 0-2cm was not significantly greater than its 10-15cm layer (Appendix 5.7). The data ranged from 4.55% (SCW) to 11.77% (± 1.63 SE) (CCW). The data were also significantly higher at the 2-5cm sites in comparison with the 10-15cm layers (CCW, RCK, SWS), and the 5-10cm was significantly higher than the 10-15cm at CCW and RCK. The deepest layer surveyed, 10-15cm, contained the least amount of OM on average for all sites combined (3.04% (±0.23 SE), ranging from 2.22% (±0.40 SE) (MTS) to 4.39% (± 0.29 SE) (MAN).

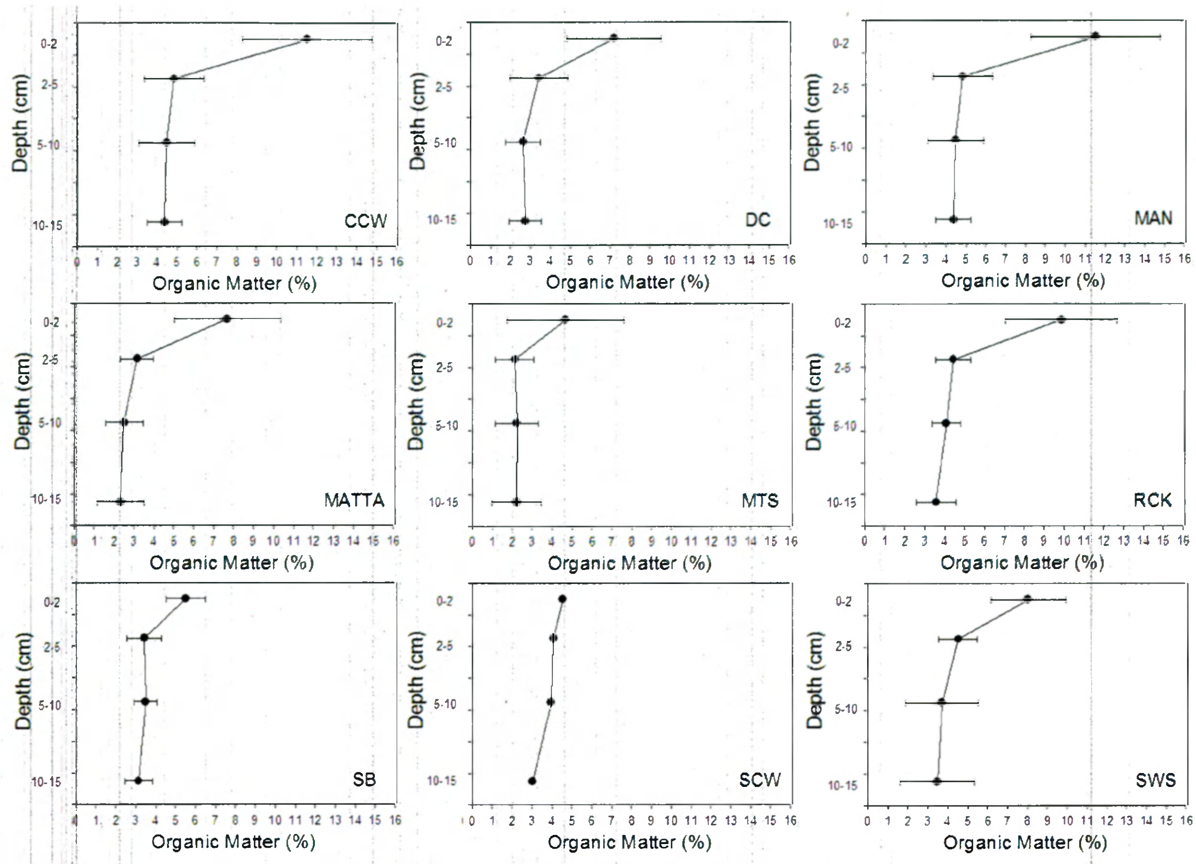

Figure 22a: Percent organic Matter for all sites by depth from the surface.

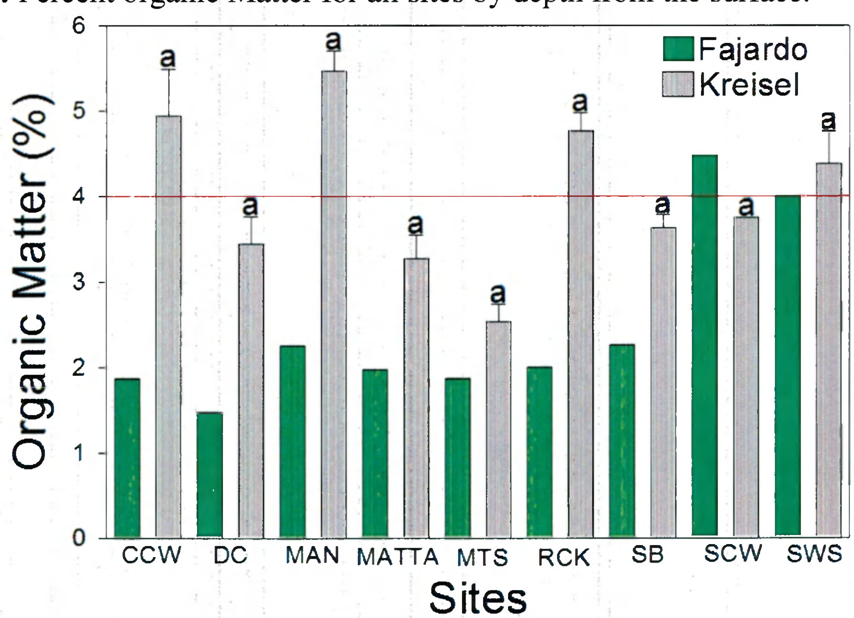

Figure 22b: Mean percent organic matter (OM) + SE by study and site from 0-15cm. The red line indicates the target 4% minimum OM level. Lack of different letters (i.e. a, b) between bars indicate no significant difference within this study ($p < 0.05$). Data regarding any significant differences within Fajardo 2006 did not exist, However, differences were significant between studies ($p < 0.008$). 4% is deemed to be the realtive standard target for mineral wetland soils (Atkinson et al. 1993; Cummings 1999).

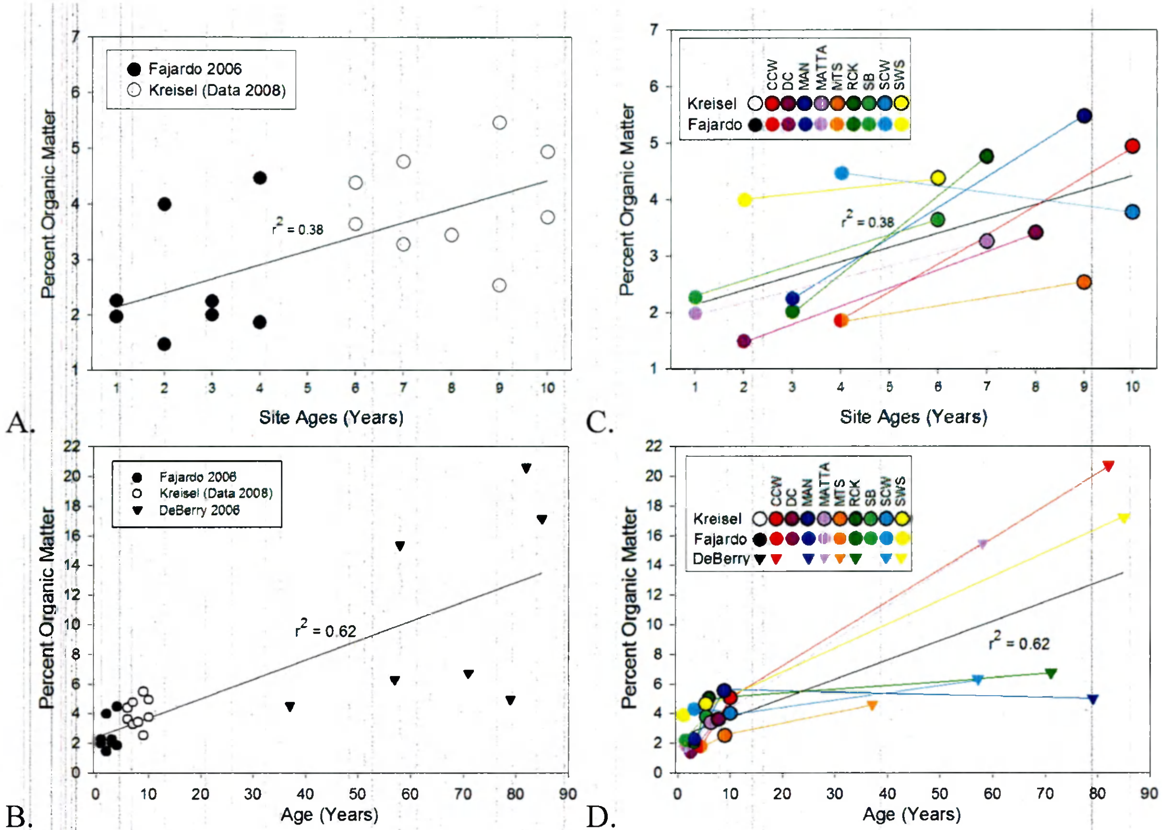

Figure 23: Organic matter content by site and study, comparison with Fajardo 2006, and DeBerry 2006 (reference sites). A) and B) Regression (trajectory) of created developmental growth. C) and D) Developmental path established by each site in this study.

2.2.3.3 Soil Chroma

Since this study did not evaluate horizons nor a full pedon at each plot, nor were 10 inches (25.4cm) of soil analyzed, the hydric status of soil at each plot and site cannot be described fully. When evaluating the chroma of the soil samples alone, a majority of the plots (54.3%) were characterized by chroma > 2 (Table 16). Additionally, nearly half of the sites (DC, MAN, RCK, and SCW*) contained 100% of plots with chroma > 2. MTS contained plots that were nearly split 50/50. Plots at three of the sites (CCW, MATTA, and SB) all contained a vast majority of plots with low chroma (66.7% to 90%). SWS was the only site with consistently low chroma in the top 15cm of soil in 100% of plots.

Between the Fajardo (2006) study and the current study soil chroma changed at almost all sites. Only three plots (MAN2, MTS4, and RCK11) retained the same chroma since the Fajardo study (Table 16). The other 78 plots were characterized as becoming either more reduced or oxidized in a nearly 50% split.

None of the sites moved uniformly towards either greater oxidation or greater reduction, as would be indicated by higher or lower chroma, respecitviely. A greater percentage of plots at CCW, MTS, RCK, and SB were more oxidized than they were in the previous study (80%, 50%, 76.9%, and 77.8% of plots, respectively). The majority of plots at DC, MAN, MATTA, and SCW* were all more reduced than they were in the previous study (66.7%, 77.8%, 90%, 100% of plots, respectively). Half of the plots at SWS became more oxidized while the other half became more reduced since the last study.

Table 16: Plot chroma and the progression of plots towards reduced or oxidized conditions^ based on soil chroma change since Fajardo 2006, as measured using the Munsell Soil Chart.
*= only one plot out of six was analyzed at SCW.

	# of Plots Moving Towards Oxidation (+) (% WHOLE SITE) ***Chroma ≤ 2 / Chroma > 2***	**# of Plots Moving Towards Reduction (-)** (% WHOLE SITE) ***Chroma ≤ 2 / Chroma > 2***	**# of Plots With No Change** (% WHOLE SITE) ***Chroma ≤ 2 / Chroma > 2***
CCW	**8** (80.0) *6 (60.0) / 2 (20.0)*	**2** (20.0) *2 (20.0) / 0 (0.0)*	0 (0.0)
DC	**3** (33.4) *0 (0.0) / 3 (33.4)*	**6** (66.7) *0 (0.0) / 6 (66.7)*	0 (0.0)
MAN	**1** (11.1) *0 (0.0) / 1 (11.1)*	**7** (77.8) *0 (0.0) / 7 (77.8)*	**1** (11.1) *0 (0.0) / 1 (11.1)*
MATTA	**1** (10.0) *1 (10.0) / 0 (0.0)*	**9** (90.0) *8 (80.0) / 1 (10.0)*	0 (0.0)
MTS	**5** (50.0) *1 (10.0) / 4 (40.0)*	**4** (40.0) *3 (30.0) / 1 (10.0)*	**1** (10.0) *0 (0.0) / 1 (10.0)*
RCK	**10** (76.9) *0 (0.0) / 10 (76.9)*	**2** (15.4) *0 (0.0) / 2 (15.4)*	**1** (7.8) *0 (0.0) / 1 (7.8)*
SB	**7** (77.8) *5 (55.6) / 2 (22.2)*	**2** (22.2) *1 (11.1) / 1 (11.1)*	0 (0.0)
SCW	0 (00.0)*	**1** (100.0)* *0 (0.0) / 1 (100.0)*	0 (0.0)*
SWS	**5** (50.0) *5 (50.0) / (0.0)*	**5** (50.0) *5 (50.0) / 0 (0.0)*	0 (0.0)
TOTAL	**40 (49.4)** *18 (22.2) / 22 (27.2)*	**38 (46.9)** *19 (23.5) / 19 (23.5)*	**3 (3.7)** *0 (0.0) / 3 (3.7)*
	Total # Plots Chroma ≤ 2		**Total # Plots Chroma > 2**
	37 (45.7%)		**44 (54.3%)**

^ = This change was based on the difference, either greater than or less than zero, when chroma from Fajardo 2006 was compared with the current study (Appendix 5.6).

2.3 *DISCUSSION*

Created wetlands are most often plagued by improper hydrology, which in turn affects the aerobic status of the soil, which in turn affects the hydrophytic status of the vegetation. While the ongoing presence of vegetation dominated by WI species still classified these nine created wetlands as wetlands, the variable hydrology across the site has continued to prevent soil chroma from dipping ≤ 2 in a majority of sites, and has also prevented the soil from becoming hydric.

As a dichotomous result of vegetative succession, and soil and hydrological properties, the sites were characterized by many new vegetative species. Some species were replacements for species, but not necessarily hydrophytic in nature. Overall, the wetland indicator status of the species served as good indicators or wetland hydrology. The inadequate hydrology has left some areas too deep, and as a result less desirable species (e.g. *Typha sp.*) replace those that are more desirable (i.e. woody vegetation).

Woody vegetation presence has increased; however dominance has not been established. Woody species cannot take root effectively in sites that are too wet, have too little OM (soil nutrients), or have high MSPD: all qualities plaguing created wetland sites.

An effective forested created wetland will require these qualities to be remedied before being effectively established. Construction efforts must ensure effective and reliable hydrology, mitigate soil compaction, utilize tillage, integrate OM amendments, plant FACW and OBL woody vegetation more than FAC, monitor sites regularly for shortfalls, and remediate where necessary. It is only with time for development and established research on shortcomings and successes that creation science can develop.

2.3.1 Vegetation

2.3.1.1 Vegetative Plot Cover

An increase in plot cover is expected in maturing vegetated systems, so the exhibited increase in many of the created wetlands shows that the sites may, in fact, be maturing (Figure 15) (Balcombe et al 2005). This previously open habitat reported in the previous study was expected to become exploited by both planted and volunteer species (Mitsch et al. 2005; Landman et al. 2007). In many cases, plot cover exceeded 100%, which was possible under the modified Braun-Blanquet cover scale (Daubenmire 1959). In most cases, this was the result of the overlap of woody vegetation over hanging the plot area, or multiple herbaceous species that were closely spaced, utilizing all of the surface area.

The decline in plot cover at SB may have been due to the low amount of surface saturation and / or the construction efforts that removed spans of invasive species at the site. Through this effort, overall cover may have been temporarily compromised. The high cover reported in Fajardo (2006) at Sandy Bottom may have been the result of invasive plant cover.

Sites that exhibited more variable hydrology across the field season and site appeared to also be characterized as generally containing more variation in plot cover amongst the site (DC, MATTA, MTS). The contrary also appeared to be true, where the sites with the least variable hydrology across both the site and growing season, also had the least amount of variation between plots for overall cover (RCK).

2.1.3.1.1 Vegetative Plot Cover Trajectory

If the developmental trajectory in Figure 17a holds true, then this increase should continue to occur until some maximum level of percent cover is reached at these sites. No data were available from the reference sites that would allow us to compare plot cover directly. However, Balcombe et al. (2005) found percent cover to be similar to reference sites after only a few years of development (Balcombe et al. 2005). Figure 17b shows the variation in trajectories exhibited by each site individually. If the individual site to be established in the future is researched fully so that the best possible construction methods are utilized, it may be possible to assume that a majority of established, created sites may be characterized by >100% total vegetative cover after ages six to ten.

2.3.1.2 Woody Vegetation

By the time that the previous study was performed, only a small to moderate amount of woody vegetation would have had time to take root and mature. Despite the fact that woody vegetation was planted at each of the sites, it was evident in the Fajardo study that a large majority of these planted trees and shrubs had failed to mature (Fajardo 2006).

While the time since Fajardo's study (2006) that has lapsed would have given the planted woody vegetation time to establish and mature, most have disappeared (Table 4, 13). I did find that certain woody species were successful (Table 14) and several have volunteered at each of the sites (Table 13). As a result of the volunteer process, there was an overall increase in the number of species since the last study (Table 11). This increased woody species richness is as would be expected in any maturing system

(DeBerry 2006). However, Landman et al. (2007) found that woody species were rare in naturally revegetating site seed banks.

Substantial changes were evident at DC and RCK where there was only a single woody species found by Fajardo (2006) at plots in the sites (*Salix nigra, Acer rubrum*, respectively). More woody species were planted after sampling. This affected the species encountered in my study since three species persisted (one and two, respectively) (Table 13). Time has allowed substantially more species to grow within those same plots. There may have been only one species, but these were the only sites to maintain their "entire crop" of woody species richness from the original study.

The Charles City Wetland contained very poor soil conditions in the previous study (Fajardo 2006); however, I found a 200% increase in woody species. Many of these saplings might have been the product of plantings rather than volunteers (DeBerry 2006), but for now the survival is the most important characteristic rather than the mechanism for its introduction. This increased survival exemplifies some improvement in soil quality (Mitsch et al. 2005b; DeBerry 2006).

Relative to other sites, SCW appears to show successful woody vegetative cover throughout the site, even if much of this was not conveyed through dominance at the site plots. D'Angelo et al. (2005) found significantly more tree biomass, compared to understory layers in late-successional forested wetlands, which may suggest that if SCW continues to increase woody vegetative cover, the site may be maturing into a forested wetland. The increase in woody cover is only better influenced by the exhibited increase in overall species richness and total plot cover, which may be a sign of site maturity (Confer and Niering 1992; Brown 1999) (Table 12). Seabloom and van der Valk (2003) found restored prairie pothole wetlands to have lower vegetative cover and species richness than natural wetland counterparts. They attributed this problem to limited seed dispersal. This site was probably influenced by the continual influx of local runoff into the pond, which may have served as both an effective seed source to increase species richness, but also as an effective source of water for the site during significant rain events. This may aid in the maintenance of wetland woody vegetation, increase of plot cover and the volunteering of new species that arise to take advantage of the environment by hindering non-wetland plant growth.

SWS also exhibited a 50% increase in woody species richness. SWS is made up of a variety of different microtopographies which allows for minor hummocks and hollows throughout the site. This keeps some parts of the site drier and some wetter, respectively. In turn, this may allow for the increased survival of greater woody species richness in areas that see water level variation (Moser et al. 2007). The second most species maintained per site from Fajardo (2006) occurred at SWS.

2.3.1.2.1 Interspecies Competition in Created Wetlands, with Regard to Woody Species

Hydrophytic species have developed morphological, and/or physiological, and/or reproductive adaptations for tolerating or adapting to the unique stressors (i.e. physical, chemical, biotic) that exist in the wetland environment (Mitsch and Gosselink 2000). Many wetland plants are adapted to the anaerobic environment with the evolution of morphological structures such as aerenchyma (e.g. *S. validus*), buttressed tree trunks (e.g. *T. distichum*), and adventitious roots (e.g. *Salix sp., Alnus sp.*). Other species produce allelochemicals to keep other competitive species away, or avoid competition completely by growing in particularly inhospitable environments to avoid competition (e.g. smooth cordgrass (*S. alterniflora)* grows in tidal salt marshes, versus tidal freshwater marshes which exhibit greater species diversity (Perry and Atkinson 1997)).

In the created forested wetland environment, competition exists for nutrients, light, and space, with the addition of elevation relative to standing water. Competition for light will become more important as the site succession develops (i.e. greater woody species cover). Other than competition for nutrients, the most prevalent problem at the sites may be competition for space relative to areas of standing water. Many areas within the sites that were "too deep" spent the entire field season underwater and were dominated by species such as *Typha latifolia*, and opportunistic (i.e. invasive) species. These areas were inundated by too much water for woody species seedlings to grow as volunteers (Ernst 1990), and may have prevented young saplings from maturing, whereas the utilization of microtopography might alleviate these issues (Bruland and Richardson 2005; Moser et al. 2007). Similarly, areas that tend to be "too dry" may become dominated by upland vegetation, since occasional soil saturation or inundation may serve as an exclusionary mechanism to otherwise prevent upland vegetation (i.e. ill adapted species) from establishing (Mitsch and Gosselink 2000).

My data showed a decrease in the total number of woody species at a third of the sites. The increased dominance of upland and invasive species at MTS and SB may be responsible for outcompeting many of the woody species at those sites. MTS contained the highest number of maintained woody species of the entire study (Table 14). Some of the woody species that volunteered were hydrophytic; however a majority that were out-competed were also hydrophytic species.

There was also a large decrease of woody species presence at Mattaponi. This might have occurred because of the construction efforts that were needed to lower the level of standing water at the site (M. Haus, VDOT, pers. comm.). Trees and shrubs may have been disturbed during construction, or the change in hydrology might have allowed other species to outcompete the woody species, similar to MTS and SB.

2.3.1.2.2 Woody Species Richness Trajectory

Figure 19 shows that if all conditions were to remain at steady-state, the sites might be expected to attain woody species richness numbers similar to reference sites, within the next few decades. An increase in woody species richness would be the first step in the transition from a freshwater marsh towards a freshwater swamp; however successive processes take a long time. This, of course, says nothing about the woody species dominance at the sites, and it may take centuries for the woody vegetation to express full dominance. Correspondingly, 44% of the sites in this study experienced a decline or steady state in total woody species richness. As a result, it may take an even longer amount of time to attain the richness, and therefore dominance levels exhibited in reference sites.

Similarly, equivalent woody species richness says nothing about diversity, which will, undoubtedly be different from the reference sites (DeBerry 2006). DeBerry (2006) concluded that, even in the oldest of created wetlands, reference wetlands were compositionally different. Compositionally, woody species richness in my sites are only somewhat similar to woody species richness in Fajardo 2006 (SI = 0.62) (Table 12), and after only a few years. Woody species at reference sites are historic relics of wetland site conditions relative to their age, rather than manifestations of recent wetland conditions

(Lopez et al. 2002), which may explain why recently created wetlands have dissimilar woody communities. Similarly, created wetland design calls for the introduction of late-successional species into immature wetland sites (Mitsch and Gosselink 2000) while the site is still experiencing high turnover of herbaceous species (Lopez et al. 2002).

Throughout all nine sites in this study, only one woody species (*Acer rubrum*) was represented as a dominant species. Very few species were maintained between Fajardo (2006) and this study, but each was listed as a hydrophytic species (2 OBL, 4 FACW, 5 FAC). However, percent cover of woody vegetation is extremely low for sites designed to be a forest (DeBerry 2006). Before a forested wetland can be realized, full establishment of hydrophytic woody species must be achieved. One promising aspect of the study regarding woody vegetation is the marked increase in the number of species per site from Fajardo (2006).

2.3.1.2.3 Woody Species Planting and Natural Recruitment

Every site in this study was planted with an assortment of woody species related to the created sites' environment, and the natural reference sites (Fajardo 2006). When comparing woody species richness across studies, many species present in Fajardo (2006) were absent from this study. Correspondingly during this time, many plots acquired both an increase in woody species richness as a result of natural recruitment, and a change in species diversity (Table 12).

Species with hydrophytic designations that were maintained over time in both studies should be primary on the list of types to plant in mitigation sites in the future. Specifically there were eleven species that successfully persisted between studies (Table 14). However, the majority of the species that persisted (55.6%) were FAC, and can be found equally in wetland and upland environments. As a result they do not represent the ideal species to characterize successful created sites.

However, it may not be necessary to plant those that have proven the potential to volunteer naturally. For example, it might prove inefficient and unnecessary to plant species such as red maple (*A. rubrum*), since not only has it proven hardy by both maintaining and introducing itself, but it is also rated as a facultative species. Since red maple also has the potential to outcompete other woody species due to its ability to grow in environments with low levels of nutrients, water, and light, using it in a planting design may have a negative effect (Abrams 1998).

It may instead prove more effective to plant hardy OBL or FACW designated species that have proven effective to ensure their site presence, such as bald cypress (*T. distichum*). Bald cypress is an obligate plant that was maintained in a third of the sites in the study. Other successful wetland trees that were minimally maintained, but were evident throughout the study, include button bush (*C. occidentalis*), black willow (*S. nigra*), pin oak (*Q. palustris*), river birch (*B. nigra*), and steeplebush (*S. tomentosa*). All of these carry FACW WI designations, and can be found along with other volunteer species that should be considered in the planning of future sites in Table 13 and 14.

I recommend these eleven species (Table 14) be considered first for planting in order to achieve more immediate, more successful survival statistics (Reinartz and Warne 1993; Balcombe et al. 2005). The introduction of more adapt, planted species might translate into more rapid accumulation of OM, better root penetration, etc. at the created sites.

The richness of FAC species should be limited to insure dominance of hydrophytic vegetation over time. Arrival and survival of another "wetter" species could be impeded by the dominance of a FAC species since it is adept at establishing in more variable types of environments. Similarly, since different wetland woody species have different flooding tolerances (i.e. deeper vs. shallower water levels, require longer vs. shorter hydroperiods), site flooding levels and planted species must be well matched to ensure survival (S. Ware, pers. comm.).

Overall, I recommend selective planting of woody vegetation to insure an early presence and fair competition for nutrients. However, due to the nature of vegetative succession, it may be in the best interest of the developer, and the site's success to delay the planting of woody species. This would ensure that site hydrology is successful, to allow the soil to develop (i.e. increase nutrient levels, reduce MSPD, etc), before investing in plantings. This would also allow for the first stages of succession to occur before introducing woody vegetative species that function in the end stages of succession (J. Perry, pers. comm.). As a result of unreliable survival rates, as exhibited in this study, the economics of site design may benefit more from a greater reliance on early-on natural recruitment, and later plantings, even if this impedes potential for early permit compliance.

2.3.1.2.4 Understory Weeding

Recent research investigated the concept of weeding the understory of woody species vegetation into the third year of development (J. Perry, pers. comm.). Weeding can eliminate any competitors for site nutrients, water, or light until the desired plants have had the opportunity to fully take root. D'Angelo et al (2005) saw significantly less understory vegetation in late-successional wetlands compared to early-succesional (< 10 year old) sites. Understory weeding may prompt a site to switch into late-successional maturation more quickly. Preliminary data show that careful planting and continued weeding at the base of trees for the first three years does not affect survival rate and allows the woody species to grow more rapidly (Perry et al. unpublished data).

2.3.1.3 Summary of Hydrophytic Vegetation

2.3.1.3.1 Study Assessment

Overall species richness at the sites within this study increased (Table 8, Figure 18). This was expected as a basic tenant of vegetative succession, as an increase in species richness up to some theoretical threshold (when it then slowly declines) is a sign of site maturity (Seabloom and van der Valk 2003; Landman et al. 2007). In essence, this is a general characteristic of succession; many species inhabit an area over time, but only a few are the final climax species (Mitsch and Gosselink 2000). I anticipate that this trend will continue for some time but as the sites begin to age, dominance of a few species will out-compete the presence of many others until levels of species richness approach those associated with each of the respective reference sites (DeBerry 2006).

Even though the vegetative community had changed drastically over time (Table 18), there was little change in the total number of dominant species (Table 9). This most likely occurred due to the lack of overall available niches across the sites. The limited niches that do exist were filled with new species that moved in and out-competed the original species. Similarly, the overall WI ratings of these introduced species were still analogous to those of the original volunteers of the sites.

Overall, there was little change in the WI status of the dominant vegetation analyzed in 2008 compared to the vegetation analyzed in 2006. This is expected since the vegetation must fit into the niches that already existed at the site/plot, assuming no drastic change in the hydrology. Many studies have shown that created sites can successfully be characterized by hydrophytic species (i.e. mean WI < 3); however in many cases, the WI of the created sites is still greater than that of the associated reference wetland (Atkinson et al. 1993; Balcombe et al. 2005).

The lack of statistical differences between Fajardo (2006) and this study implies that no significant changes have occurred in the number of species in the vegetative communities over the last five years. However, the increased woody species richness, and increased species richness and density are appreciable characteristics that show that the sites are maturing.

2.3.1.3.2 Site Assessment

In Fajardo 2006, three of the sites (MTS, SCW, SWS) were deemed to contain good vegetative cover and hydrophytic dominance. The other six sites either contained too little cover to be successfully assessed, or were merely deemed "ok" with references to areas that were "too wet" or "too dry" (Daniels et al. 2005). In this study, most of the sites have maintained the dominant species and a WI status average characteristic of jurisdictional wetlands. Correspondingly, many of the plots maintained hydrophytic status (Table 10). The successful hydrophytic vegetation may have been maintained on the small time scale due to better site hydrology, and developing soil conditions.

In my study, two sites, SB and RCK were each characterized by a WI status that was too high to consider them jurisdictional wetlands. MTS and RCK exhibited the greatest decline in percent hydrophytic plots over time since Fajardo (2006). These three sites may share similar site morphologies that keep them relatively drier, since they were characterized by three of the highest WI, and were at least partially dominated by UPL vegetation in the field season. As a result of site morphology (and hydrology), upland vegetation may have a competitive advantage over hydrophytic species. Certain plots may require further remediation since they are not in compliance with mitigation efforts and legislation. A shallower slope and lower surface at RCK1 and RCK2, for example, would allow the water table to better reach the surface, and possibly prevent upland vegetation from dominating these areas.

2.3.2 Hydrology

Throughout the growing season, vegetation absorbs water from the ground for photosynthesis, therefore it was expected that the plots would be consistently drier during the growing season than they would be during the winter. This was consistent throughout this study as well (Table 15, Figure 20).

The plots and sites that were consistently wetter were also characterized by comparatively "wetter" vegetative species. In many cases, this prevented non-wetland type vegetation from settling. If the plot was too wet, in many cases it became dominated by near-monocrops of *Typha latifolia* (Grace 1987; Atkinson et al. 2005), which was similarly undesirable. Great care should be taken to prevent this in the future. Perhaps it can be avoided by making sites slightly deeper (i.e. wetter) than needed when the main source of hydrology is surface runoff or from a stream. In this way, if the site continues to be too deep, the source can be partially diverted to achieve correct levels. When groundwater is the source of hydrology, preliminary water table level data may need to be reviewed for a longer period before site construction can begin. Another more difficult option is to adjust the elevation of the site (ex: MATTA) by importing more surface material; this would decrease depth of groundwater inundation relative to the water table.

2.3.3 Physical Soil Properties

2.3.3.1 Modified Soil Particle Density (MSPD)

Eight of the sites were characterized by relatively large, significant decreases in MSPD since the last study ($p < 0.021$) (Figure 21b). Many sites that were once root-limiting at varying depths between zero and 15cm now are approaching more reasonable values that allow for better root penetration, and would then allow for growth of vegetation and woody species in the future (Nair et al. 2001).

2.3.3.1.1 Equipment Construction Compaction

MSPD can vary with the initial construction methods utilized to develop each of the sites. In all cases, the construction companies employed the use of heavy machinery to excavate or fill-in the soil as necessary in order to develop each of the sites to the specified depths. This impact of the machinery's weight and pressure compact the in-fill, or newly-exposed soil medium. The resulting soil is much less able to be penetrated by macrophytic roots, faunal burrowing, or water infiltration due to the decreased pore spaces. Even before being exposed, sub-surface horizons are relatively more compact, so this may synergistically amplify the effect. Products on the market, such as equipment mats, claim to give safe access for construction and protect the surrounding environment in the process, specifically in wetlands. I recommend that these products be studied further in order to evaluate their potential for alleviating soil compaction which otherwise continually plagues newly created systems.

2.3.3.1.2 Cut versus Filled Sites

Much of the soil that was used to fill-in sites had been stored, or moved from other locations. Soil structure provides pores for both water and gas movement within the horizons. But the structural elements are delicate, so any movement most likely puddled the aggregates (i.e. weight of tilling wet soil causes the soil to lose aggregation). On the other hand, cuts sites lose the soil that once *contained* those aggregates, and deeper horizons become puddled from the weight of upper layers as well. Employing tillage mitigates the puddled aggregates and compaction in both cut and filled sites, but only to a limited degree. Fajardo (2006) also noted that any variation observed in MSPD should probably not be a factor of employed tillage, as there was little variation in its practice. Tilling should be continued in future mitigation site constructions in order to continue its benefits.

Overall, there were no apparent initial differences in the young sites in Fajardo (2006) in soil MSPD between sites that were created by soil in-filling (SB, SCW, SWS) (1.59g/cc), versus those that were cut to depth (CCW, DC, MAN, MATTA, MTS, RCK) (1.54g/cc) (Figure 21b). However, with time, cut sites may have lower MSPD (on average 1.36 g/cc, cut; versus 1.48 g/cc, fill) (Figure 21b), although this difference did not vary significantly.

The data seem to show that cut sites, while still constructed with heavy machinery, may be characterized by a lower MSPD in a shorter amount of time than filled sites. The removal of soil in cut sites allows the stable, but structurally puddled soil in cut sites to maintain the pore spaces that have developed at that depth. This study reports that filled-in sites tend to have more compacted soils (although not significant)

(Figure 21b) because the aggregates that might have otherwise existed in soil brought to the site are disturbed in the movement and construction process. Many pores in the soil are eliminated as a result. Relative to cut sites, filled sites also tended to have a lower nutrient composition (although not significant) (Chapter 3). This may also be an artifact of the MSPD issues since greater pore space influences the microbial biomass and vegetative growth which in turn affects the nutrient development at the sites.

However, from a land-use stand point, many of the filled-in sites in this study were actually mines that were being reclaimed. The benefits of reclaiming sites might outweigh the lesser issue of MSPD, since neither creation method appears to truly hinder development. As a result, while in their first decade there may be a lower MSPD in cut sites when compared to filled sites, filling-in sites prevents wetland construction on an otherwise usable space, and remediates an otherwise unusable one.

If a developer were *solely* considering the soil and vegetative characteristics evaluated in this study, then I must recommend that the mitigating authority invest in cut sites for the faster return on their investment in creating a site. However, when considering the overall environmental impact of the site, it might be better to consider developing filled sites (or a combination site thereof). In doing this, a location that is already an environmental scar on the landscape could instead be remediated into becoming a more environmentally appealing location. The possible delay in meeting the mitigation requirements may be well worth the wait.

2.3.3.1.3 Root Limitations and Depth Evaluation

MSPD becomes root limiting when values approach the range of 1.45g/cc to 1.75g/cc depending on the texture of the soil(fine – coarse loamy, respectively) (Daniels and Whittecar 2004; Brady and Weil 2008). Fajardo (2006) found nearly half of the sites to be root-limiting (CCW, DC, MAN, and SB). Since texture was not evaluated in this study, I was not able to make a full current examination of root limitation. However, an estimation of root limitation can still be evaluated based on comparisons with literature values. Accordingly, neither the 0-2 cm nor 2-5 cm layers from any site in this study could be considered root limiting. However, at greater depths, both MSPD and root limitation increase in all sites, and at 10-15cm all sites could be considered root limiting (Figure 21a).

Root limitation was also evident by the lack of OM present in the deeper samples. A lack of OM would indicate a lack in vegetation as well. A considerable amount of OM was present in surface samples, with noticeably fewer roots in the lower soil layers sampled in this study (specifically below 5cm). Given that I observed few roots at the deepest sampled depth, it is highly probable that deeper horizons hold even higher MSPDs at each site. My findings were similar to those of Nair et al. (2001) who showed that created sites contained high MSPD relative to natural sites, which at 10-20cm (depending on site age) approached penetrometer readings considered critical to root penetration. As a result, they concluded that soils with lower MSPD would support better vegetative growth.

MSPD is consistently higher in the subsurface layers because so much time and physical action is required to break down the deeper layers. Pores are more easily created at the interface between soil and air versus layers below ground. Density is more variable (and lower) at the surface levels because water and flora are much better able to penetrate through and loosen up the soil particles (Figure 21a) (Brady and Weil 2008).

Organic matter and MSPD tend to vary inversely (Nair et al. 2001; Brady and Weil 2008). Much more organic matter occurs in the surface layers than in the subsurface layers, as demonstrated by the decrease in both general size, and volume of root material with increasing depth (Appendix 5.6). Lighter and fluffier organic material recreates air pores and decreases weight by replacing the space otherwise occupied by soil particles, therefore greater amounts of OM also decrease MSPD (Brady and Weil 2008).

MSPD can be naturally decreased over longer periods of time via macrophytes, and micro- and macrofauna. Earthworms, for example, ingest soil at shallow depths by day, and eliminate aggregated, organically amended lighter pellets by night (Brady and Weil 2008). While in search of soil moisture, plants root hairs expand into lower horizons of the soil profile and thereby increase pores throughout the lower reaches (Brady and Weil 2008).

2.3.3.1.4 Site Evaluations

Among all study sites, MSPD was highest at SB, which may have been due to a combination of factors. The site was surveyed in Fajardo (2006) only a few months after the site's construction. SB was one of only two sites to have been surveyed so quickly (within months), and to have received extra construction efforts (between studies). SB received extra remediation to address the growth of many invasive and upland species, such as *Lespedeza sp.* Extra construction equipment associated with remediation may have exacerbated the issue with MSPD, which when combined with low levels of saturation and standing water at SB may have prevented wetland vegetation from establishing at the site. This, in turn, may have prevented MSPD from declining even more.

Time and the interplay of both hydrologic and organic (faunal and floral) factors facilitated the successful decrease in MSPD for a majority of the sites. RCK may be expressing the slowest change in MSPD over time. Many plots in RCK are plagued by upland-type vegetation, and correspondingly, limited overall hydrology. SCW, which was much more successful in terms of vegetation and hydrology, oddly enough shared characteristics with RCK, having experienced similar depressed rates of change in MSPD. This might merely be due to an artifact of the sampling inadequacies. The only plot that was sampled for soil characteristics was the one lying farthest from the pond and stream within the site. If more plots had been sampled, I am confident that this value would have decreased as a site.

2.3.3.1.5 Anticipation of Modified Soil Particle Density (MSPD)

Fajardo (2006) concluded that time and relative % OM were the dominant factors related to MSPD values, based on limited site sampling. Knowledge of limited OM amendment appeared to explain the root-limiting values. My study concurs with the finding that OM was one of the best predictors of MSPD. However, while time does play a role in determining relative MSPD values (Nair et al. 2001), the sites in these studies may be too young to implicate age as a measure of MSPD since age was rather inconsistent with actual MSPD values in this study. It is very possible that with more time, a comparison based on age will be possible. Other factors that may have contributed to a decrease in soil MSPD in this study, in addition to % OM, include an increase in soil C, N, (which is inherently related to the OM) and porosity, as measured by soil moisture.

Many sources have emphasized the importance of anticipating soil compaction issues when mitigating sites in order to maximize functional success (Whittecar and

Daniels 1999; Nair et al. 2001; Hogan et al 2004; Norfolk District Corps and VDEQ 2004; Brooks et al. 2005; D'Angelo et al. 2005; Fajardo 2006; Bailey et al. 2007). However, in practice the importance of soil preparation still seems to be under-acknowledged by developers. Soils tend to become compacted beyond functional viability during construction. I agree with the recommendation produced by Fajardo (2006), that soil should be ripped below surface horizons in order to prevent long-term MSPD and root limitation problems. Fajardo (2006) hypothesized the continued hindrances to soil development that were still evident in this study. I believe that as the soils continue to develop, density will continue to adjust to levels at or below those of natural mineral soils (1.25 g/cc) (Figure 26b).

2.3.3.2 Organic Matter (OM)

Overall, four sites of the sites that maintained the wettest hydrologic conditions throughout the study also maintained the greatest % OM (i.e. CCW, MAN, SCW* and SWS) (Figure 20, 22b). The decreased rate of oxygen diffusion through inundated soil prevents microorganisms from breaking down organic litter. As a result OM builds in the soil, and so net OM sequestration occurs under anaerobic conditions.

As a result of the steps and processes required for its maintenance, OM tends to be one of the more important, and most researched wetland indicators of function (Atkinson et al. 1993; Bishel-Machung 1996; Stolt et al. 2000; Bruland and Richardson 2004; Balcombe et al. 2005; Brooks et al. 2005; D'Angelo et al. 2005; Daniels et al 2005; Bridgham et al. 2006; Fajardo 2006;). As previously mentioned in Chapter 1, 4% OM is deemed the relative standard target for mineral organic wetland soils since that is the reference natural forested wetland average (Atkinson et al. 1993; Cummings 1999). From this, I can conclude that seven of the sites have acquired successful soil OM levels, on par with natural sites (CCW, DC, MAN, RCK, SB, SCW, SWS) (Figure 22b). As a study, the sites can be characterized as containing significantly more OM than in Fajardo 2006 ($p < 0.008$).These sites now have the potential for growth from which to better improve other properties such as vegetation (DeBerry 2006) and microorganism quality.

2.3.3.2.1 Organic Matter Amendments

Five of the sites in this study had been amended with OM during their initial construction (MATTA, RCK, SB, SCW, SWS), and nearly all of them are included in the group that has met that 4% level (MATTA contains 3.27% OM).The sites that were not amended with OM during original construction (CCW[3], DC, MAN, and MTS) (Table 3) were characterized by lower % OM in Fajardo (2006)[4] and this low level perpetuated into this study, specifically in DC and MTS. The other two sites, however – CCW and MAN– contained the highest % OM in this study. Between studies, CCW had been amended and re-graded (L. Snead, VDOT, pers. comm.) so this increase was not entirely "organic" in nature. DC and MTS were some of the driest sites in the study, and without amendments the site continued to be plagued by low soil OM. On the other hand, CCW and MAN were some of the wettest sites in this study over the course of the current study and therefore under the most anoxic conditions. While characterized by low soil OM in the previous study, current data characterize CCW and MAN with the highest % soil OM of the entire study.

[3] Site received OM amendment after being sampled in Fajardo 2006.

[4] Given the fact that % OM content of this study was determined through weight loss on ignition, and %C data from the Fajardo study was extrapolated using an overestimating conversion factor of 0.58 (Nelson and Sommers 1982), there are inherently some basic differences in the level of %OM in each of the studies. This may explain why there existed such significant differences between studies. These figures cannot be completely off, since they relatively equate to the total carbon data from each of the studies.

The data from this study appear to show that the more favorable levels of physical soil characteristics (OM, MSPD) and %C (Chapter 3)) were found in amended sites, whereas more favorable levels of other nutrients (N, C:N, Fe, P (discussed in Chapter 3)) were found in the un-amended sites. However, none of these differences were significantly different. I believe that the data may represent either a reduced rate of nutrient accumulation in amended sites, or an increased rate of nutrient utilization by site vegetation. A majority of these characteristics (all except C:N and MSPD which was negligible) were more favorable in amended sites at the time of amendment (Fajardo 2006). I believe that the rate of growth in un-amended sites must have begun more slowly, and have increased over time.

As mentioned in Chapter 1, the literature strongly recommends integration of soil OM amendments in the upper soil layers as an important step to jumpstart microbial growth and soil nutrient development for both increased soil reduction potential and vegetative growth. From these data and observations it can be concluded that OM amendments and proper hydrology may contribute to more rapid early wetland development, whereas a lack of amendment and/or poor hydrology may hinder early site development.

2.3.3.2.2 Site Evaluations

Surface layers of soil should have a greater amount of OM than the subsurface layers (Anderson et al. 2005), since a majority of vegetative matter grows above the soil, or in surface layers, and at the end of the growing season this material would fall on the surface layers (Figure 22a). Activity of microorganisms is required over time to break down the OM and integrate it into the subsurface layers. And so, at all sites, soil surface

OM was significantly higher than deeper layers[5]. Consequently it is not surprising that there is a direct trend between depth and OM at both individual plots and sites (Nair et al. 2001). CCW, MAN, RCK, and SWS had the highest percent OM for each respective depth when compared to the other five sites. CCW, MAN, RCK, SCW, and SWS contained the target 4% OM level in many subsurface levels.

Many studies have shown that there is a positive relationship between soil OM and age in relatively young sites (Nair et al. 2001; D'Angelo et al. 2005; and Daniels et al. 2005). Data from the current study confirm those findings. Many sites in this study have more than doubled the total amount of soil OM since previously sampled.

Other prior studies, however, found no significant relationship between soil OM and site age (Bishel-Machung 1996; Giese and Flannagan 2006). However, Giese and Flannagan also noted that a relationship in young sites may not be evident for some time since soil OM accumulation is a slow process. In the Fajardo (2006) study, sites were sampled either shortly after wetland creation, or into the sites' first few growing seasons, whereas now the sites have had more time to develop. These non-standardized sampling times among sites may explain why some sites exhibited significant OM accumulation (MAN) and others had a much less substantial increase (SB, SWS) (Figure 22b, Table 3).

2.3.3.2.2 Organic Matter Trajectory

When evaluating % OM, the data show that sites take years to accumulate OM. The rate of increase tends to decline as OM levels increase, and in comparison with reference sites, created sites take decades to approach numerical equivalency. While Figures 23b and 23d show a linear progression of nutrient accumulation, I think that the

[5] The one exception was SCW, which cannot fully be accounted for due to a lack in data.

accumulation will better resemble a logarithmic curve, with more significant accumulation in the first few decades, and then tapering off once the natural levels are approached.

Figure 23 appears to show multiple stable states associated with the natural reference sites. The reference sites to the relatively dry created sites, especially MTS, RCK, SCW (before beaver activity) contained between 4.5% (MTS) to 6.7% (RCK) OM, and were between 37 years old (MTS) and 79 years old (MAN) (DeBerry 2006). These created sites have reached their respective goals for soil OM content. The reference sites to the relatively wet created sites, (CCW, MATTA, SWS) contained between 15.4% (MATTA) to 20.6% (CCW) OM, and were between 58 years old (MATTA) and 85 years old (SWS) (DeBerry 2006). The associated created sites will require decades to centuries to have the potential to become equivalent to the counterparts. This elucidates the dilemma regarding how "wet" a site should be made. Here, referencing a wetland that tends to be drier lowers the goal as to how much OM needs to accumulate before the site can be determined to be successful. On the other hand, sites that tend to be wetter will both be able to accumulate more OM, and need to in order to be compliant, should OM accumulation be a permitting goal.

Organic matter is often utilized as proxy data to assess the degree of hydric soil formation in created systems (Campbell et al. 2002; Fajardo 2006). Consequently OM is regarded as an overall predictor of functional equivalency, and thus the OM trajectory is especially important. I predict that levels of OM should continue to improve in the soil system with increased site age, so long as overall conditions remain favorable at each of the sites.

2.3.3.4 Soil Chroma

In some cases, the hue of soil examined in this study differed slightly from that exhibited in Fajardo (2006). This may have been due to the nature of the sampling methods, as hue was not evaluated immediately in the field, as it was in Fajardo (2006).

A majority of the plots in this study were characterized by chroma of > 2 and so these plots would fail to indicate a jurisdictional wetland soil (hydric soil), had the correct horizon or depth been analyzed (Table 16). Frequent and consistent inundation produces anoxic conditions in the soil when microorganisms use up the limited supply of oxygen. Unique flora and fauna have adapted to living in these harsh conditions. Microbes that thrive under anoxic conditions utilize terminal electron acceptors (TEAs) other than oxygen which help to deplete the colors of the soil matrix (Mitsch and Gosselink 2000; Brady and Weil 2008).

Wetland plants are also adapted to low-oxygen environments and are able to transport oxygen into their systems from above the soil surface. Oxygen is often leaked into the soil matrix from root hairs. Iron-oxidizing bacteria take advantage of this leaked oxygen and create bright red, oxidized root channels (Mitsch and Gosselink 2000; Brady and Weil 2008). These redoximorphic features – oxidized channels surrounded by the depleted matrix –were the most common hydric soil indicators of my study.

In many cases, relatively more inundation, and domination by wetland species were consistent with a higher percent of plots exhibiting lower chroma. This was especially evident in sites like CCW, MATTA, and SWS. On the contrary, sites that were relatively dry for the duration of the growing season and were dominated by species of upland vegetation (MTS, RCK, SB) were characterized by plots with high chroma and/or no other redoximorphic features.

High iron content in the form of highly oxidized Triassic red soils in sites like MAN left the chroma higher (avg. site chroma of 4) (Table 26, 27). As a result, this very wet site fails the hydric soil criterion that chroma be ≤ 3 (for Triassic red soils). In fact, MAN had the reddest soils (qualitatively) and highest iron content of all sites in the study (quantitatively) (Chapter 3). Overall though, MAN did see a decrease in chroma at many plots.

Without a full assessment of the pedon and/or deeper horizons at the plots, a full analysis and study comparison of hydric soil status is impossible.

The relative classification of sites as being low or high chroma soils is comparable to the trajectory of the plots becoming more oxidized or more reduced (Table 16). Sites that contained the least amount of soil saturation over the field season were characterized by low chroma, but have also become more oxidized since the last study. The longer periods of saturation over the field season may be responsible for creating the optimal conditions necessary for anoxic development.

The plow pan or traffic pan at CCW is still impeding infiltration; however since the chroma in many plots have increased, the soil may be less resistant in some areas since the last study. There also may have been less precipitation at the site than before sampling in the Fajardo (2006) study since this was a relatively dry summer. Most of the sites with more consistent hydrology seem to be on a trajectory of decreasing chroma (Figure 20, Table 16).

The lack of uniformity within sites, of solely oxidized or reduced plots (Appendix 5.6), may exhibit variable microtopography among the different plots within those sites. The hummocks and hollows may allow for species richness by creating areas that drain at different intervals throughout the growing season. Studies have shown that richness does in fact increase where hummocks and hollows are included in the design (Bruland and Richardson 2005; Moser et al. 2007). However, this variation is often considerably less than that expressed in reference wetlands (Whittecar and Daniels 1999). Microtopography allows species with different life strategies to separate into specialized niches where they have the potential to outcompete less specialized species (Moser et al. 2007).

2.4 *CONCLUSIONS*

In summary, a majority of the sites have begun to show signs of vegetative succession and site maturation towards natural reference site characteristics through increased plot cover (all except SB), species richness (all except SB), and woody species richness (all except MATTA, MTS, and SB) . Similarly, signs of increases in OM (all sites except SCW*), and decreases in MSPD (all sites except SCW*) may continue to synergistically improve conditions for site and greater woody species development. These physical soil conditions, in conjunction with decreasing chroma at sites (≥50% plots having ≤ 2 chroma (CCW, MATTA, SB, SWS) exemplify signs of site maturity at these created wetlands. In developing new sites, we recommend selecting sites to be filled rather than cut, where possible, minimizing vehicle traffic on site surfaces, utilizing organic amendments in all cases, and planting hardy hydrophytic woody species.

Further evaluation of these sites approximately every five years is crucial to continue to develop a baseline data set of developmental characteristics; however certain sites may first require remediation (e.g. RCK1, RCK2, and MTS1). Further investigation comparing natural reference site characteristics to created sites is important (e.g. SI, overall plot cover, woody versus herbaceous cover and IVs). An evaluation of surrounding land use relative to native/introduced species may confirm that sites surrounded by developed land may be susceptible to more introduced species (Magee et al. 1999).

Chapter 3. Soil Chemical Properties

3.1 *METHODS*

Site descriptions and general field methodology are described in Chapter 2.

3.1.1 Soil

Using an open-barreled syringe, 5cc sub-samples were acquired from the bagged bulk soil sources, freeze-dried using a Labconco Freeze Dry System/ Freezone 4.5, and then ground with a mortar and pestle. Total P was extracted using the ashing / acid hydrolysis method of Chambers and Fourqurean (1991). Extracts from the Total P samples were analyzed using the ascorbate method for SRP. Total C and Total N were determined on a Perkin Elmer 2400 Series II elemental analyzer; C:N ratios were calculated. Amorphous Fe was estimated using a hydroxylamine hydrochloride extraction (Chambers and Odum 1990). Soil characteristics for 0-15cm for C, N, CN, P, and Fe were obtained from the weighted average results of the four depth increments analyzed. The results for C, N, and C:N were then compared against Fajardo (2006). Fajardo (2006) analyzed P and Fe using a less rigorous method, so a comparison between studies was not possible.

3.1.2 Statistical Analysis

All comparisons of the measurement variables among studies, sites, and depths were analyzed using SPSS System for Windows, Version 17.0 (2008), setting the level of statistical significance at $p \leq 0.05$.

For data that were non-normally distributed, statistical comparisons between variables were evaluated using the PASW System for Windows, Version 17.0.2 (2009).

The Wilcoxon Rank Sum Test was used to compare all variables examined in this study between sites (e.g., comparing % C data between all sites in this study). The Wilcoxon Signed Rank Test was used to compare variables between studies (e.g., comparing % C data at CCW of this study, to the data from Fajardo 2006), and to compare single variables within a plot at different depths (e.g., comparing % C data at CCW1 between 0-2cm and 2-5cm). In this manner, covariance effects are removed from the test. Both nonparametric tests are based on the assumption that data arise from randomly selected pairs that are matched up (Motulsky 1995). Neither test assumes normal distribution but both allow for smaller sample sizes than their t-test counterpart (the two-sample, and paired t-tests, respectively).

Linear regression and Pearson correlation were used to examine the temporal trends in soil parameters.

3.2 *RESULTS*

3.2.1 Total Carbon

The Fajardo study showed that the study sites had an average of 1.43% C at each site. In the current study, the average for all sites rose to 1.68% C (± 0.11 SE) (Figure 24b). Although most sites tended toward an increase in % C, this relationship was not significant ($p = 0.110$).

The highest levels of C in the Fajardo study were found in SCW (2.59%) and SWS (2.32%). All other sites had ~1% Carbon. The highest % C in my study was found in SWS (2.52% (± 0.21 SE)). All other sites had soil C < 2%, with SCW* the least at 0.88%. SCW had significantly less % C than MATTA, SB, and SWS ($p \leq 0.029$), but %C among remaining sites was not significantly different.

The surface layer (0-2cm) was higher in %C relative to lower soil layers in every site, ranging from 1.21% (SCW*) to 4.24% (± 0.53 SE) (CCW) (Figure 24a, Appendix 5.7). The 2-5cm layer was also significantly higher than the lower layers except at MATTA and SWS (5-10cm), and DC (10-15cm). Additionally, %C was significantly different between 5-10cm and 10-15cm at both CCW and RCK.

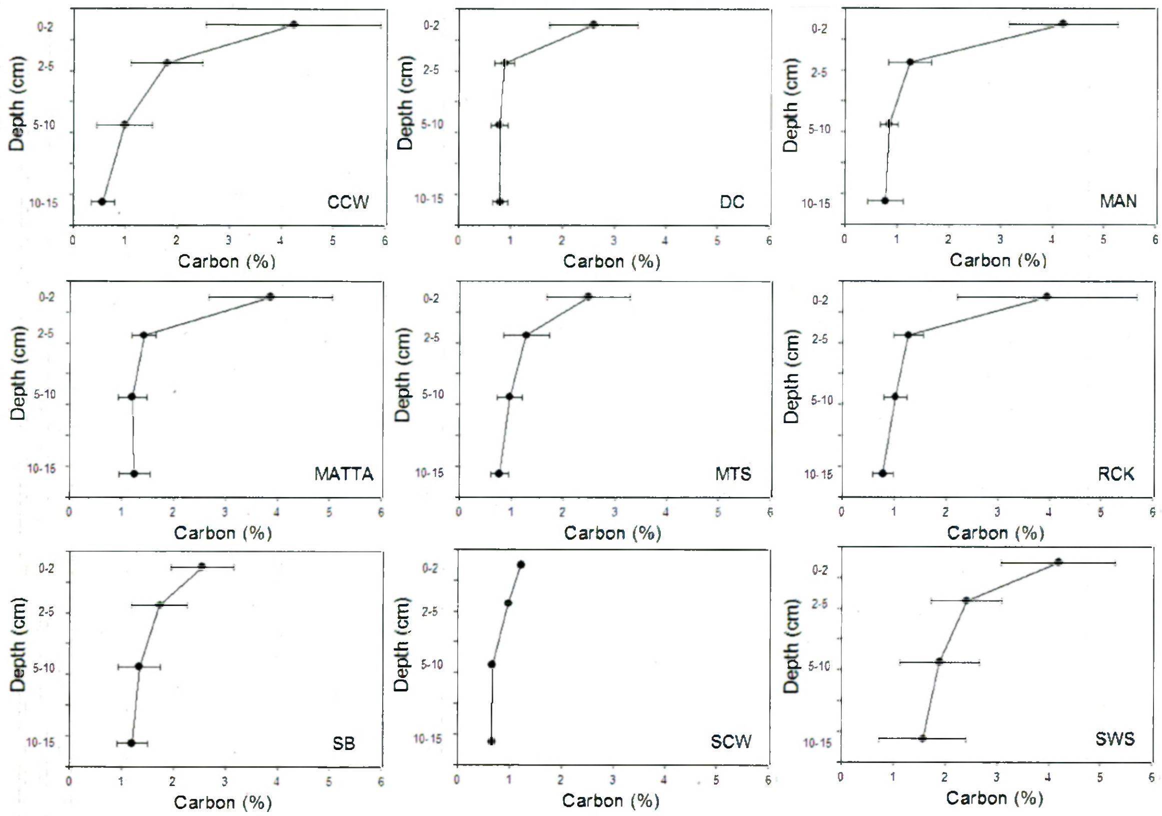

Figure 24a: Percent carbon for all sites by depth from the surface.

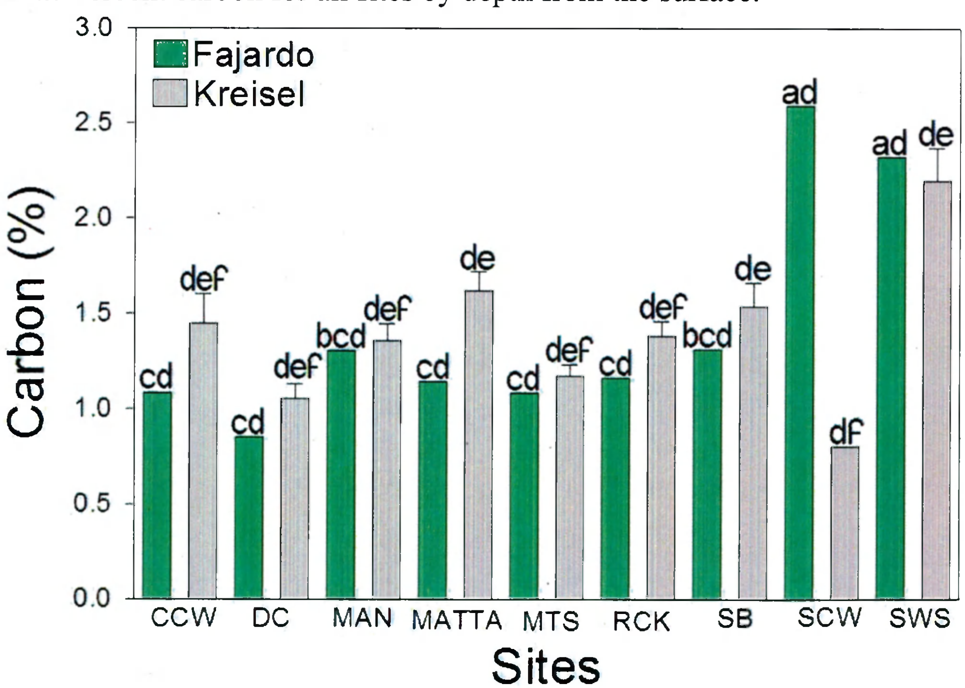

Figure 24b: Mean percent carbon + SE by study and site from 0-15cm. Different letters between bars indicate a significant difference within this study ($p < 0.05$). Significant differences existed between sites within in Fajardo 2006 (a - c); and within the current study (e - f). Comparing all sites across studies, however, yielded no significant difference ($p = 0.214$).

3.2.2 Total Nitrogen

In the Fajardo (2006) study, Total N ranged from 0.08% (DC) to 0.17% (SWS). At that time, SWS had significantly more N than the other sites. Data from my study indicated that Total N increased significantly from the previous study ($p \leq 0.011$) (Figure 25b). In most sites, Total N levels actually doubled since the last study. Total N levels now ranged from 0.08% (SCW*) to 0.24% (± 0.02 SE) (SWS) overall. In the reference sites, Total N ranged from 0.164% (MTS) to 0.690% (CCW) (Figure 26).

Consistently, the 0-2cm soil layer was the highest in %N (Figure 25a), ranging from 0.11% (SCW*) to 0.41% (± 0.13 SE) (SWS). Total N was significantly greater at 0-2cm when compared to all subsurface levels in each site (Appendix 5.7). Similarly, the 2-5cm layer was also significantly higher from the lower layers at a majority of the sites. Only SB contained significant differences between the 5-10cm and 10-15cm layers. Regardless, there was an overall trend that showed that total N decreased with depth. In addition, SCW contained significantly less % N than DC, MTS, and SWS, while there were no statistical difference between the remaining sites ($p \leq 0.029$) (Figure 25b).

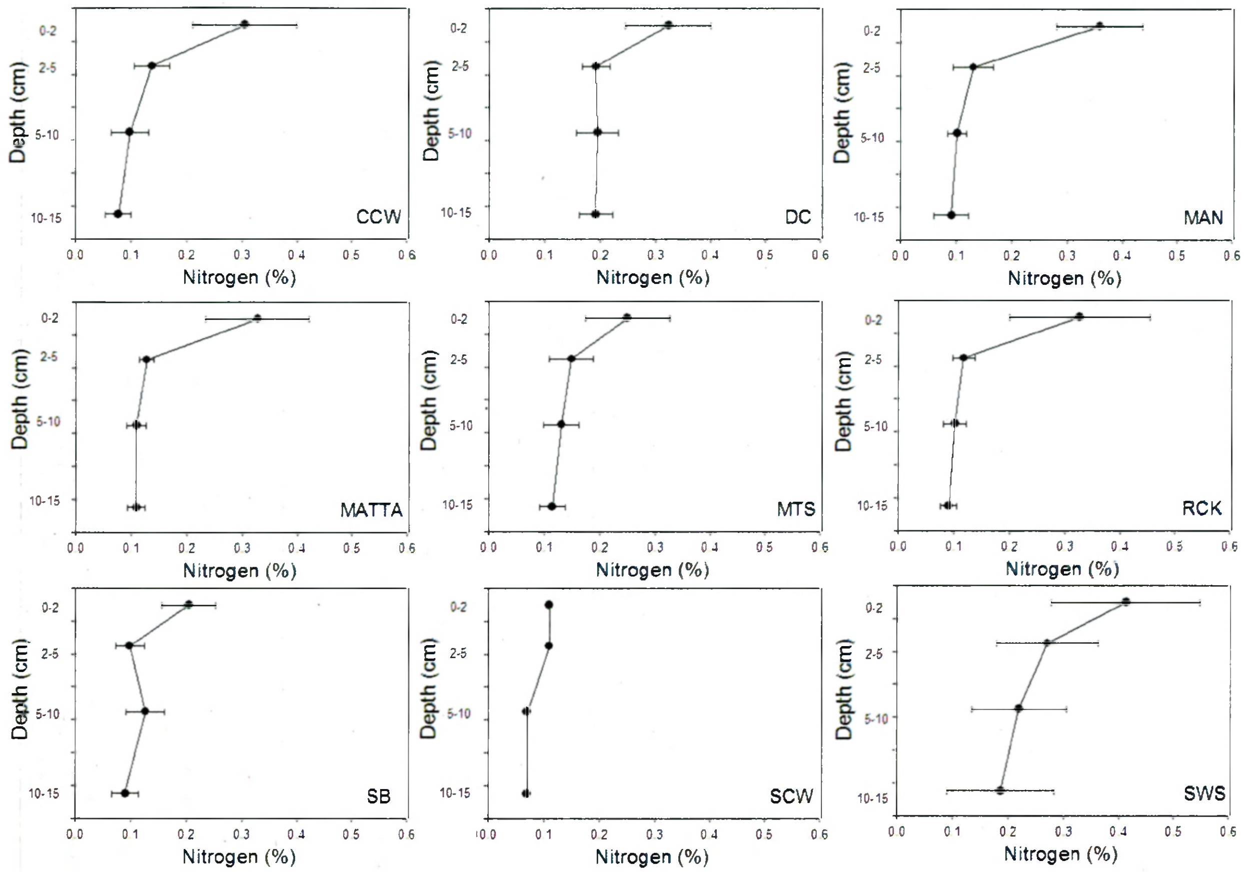

Figure 25a: Percent nitrogen for all sites by depth from the surface.

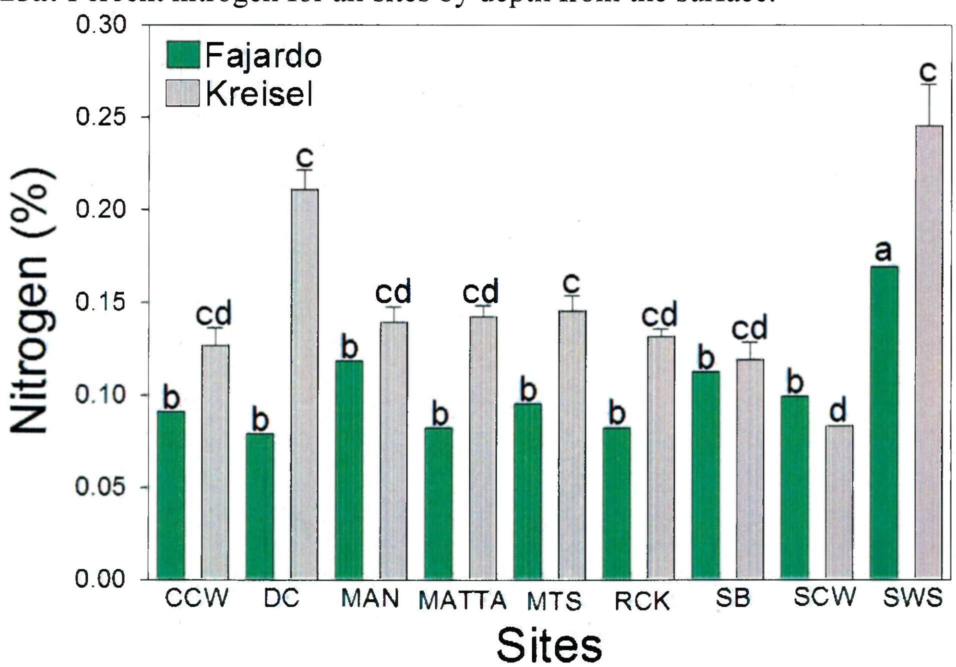

Figure 25b: Mean percent nitrogen + SE by study and site from 0-15cm. Different letters between bars indicate a significant different between sites within Fajardo 2006 (a, b), within the current study (c, d) and between studies ($p < 0.015$).

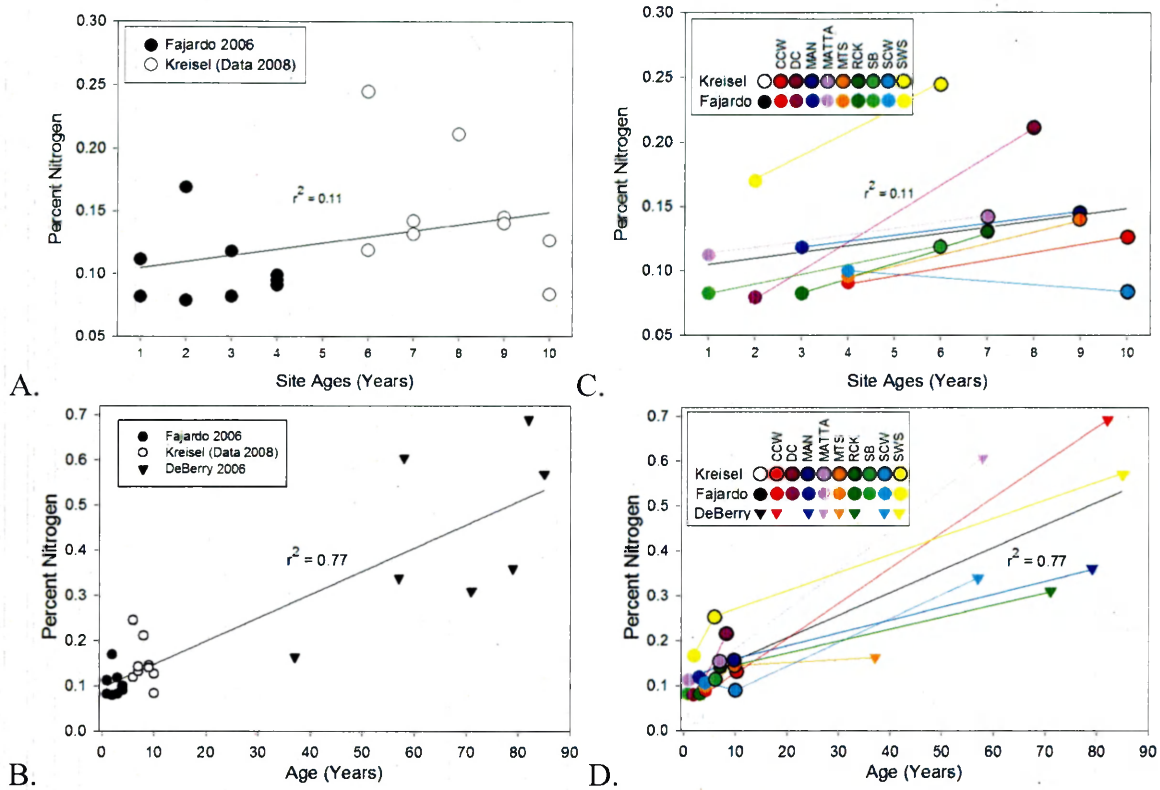

Figure 26: Total Nitrogen by site and study, comparison with Fajardo 2006, and DeBerry 2006 (reference sites). A) and B) Regression (trajectory) of created developmental growth. C) and D) Developmental path established by each site in this study.

3.2.3 Carbon to Nitrogen (C:N) Ratio

In Fajardo's study, soil C:N ratio ranged from 10.7 (MAN) to 24.7 (SCW). SCW had a significantly higher C:N than the other sites ($p < 0.0001$). Overall, my data show a significant decrease in C:N relative to the Fajardo study ($p \leq 0.008$) (Figure 27b). The ratios in the current study ranged from 4.7 (± 0.3 SE) (DC) to 13.4 (± 0.6 SE) (SB). In Fajardo 2006, the mean C:N was 14.40, and now this value has decreased to 9.41 (± 0.38 SE). DC contained a significantly lower C:N from all sites except CCW and MTS ($p \leq 0.029$). SB and MATTA were both significantly higher than SWS and MTS ($p \leq 0.029$).

The Fajardo study documented significant differences in C:N ratio between depths (0-15cm vs deeper layers), and that trend continued into my study. C:N decreases with depth in most sites (Figure 27a), with the difference significantly higher between the surface (0-2cm) layer and most of the subsurface layers in a majority of the sites (Appendix 5.7). Surface layers ranged in C:N from 7.9 (± 0.41 SE) (DC) to 13.7 (± 0.55 SE) (CCW). The only sites with no statistical differences between surface and deeper layers were CCW and SWS (2-5cm), SB (5-15cm), and MATTA where nothing was significant. The C:N difference was also significantly higher at the 2-5cm layer and the subsurface layers at CCW, MAN, MTS, and SB. RCK 2-5cm was significantly higher only at the 10-15cm. CCW, RCK and SB contained significantly higher 5-10cm C:N at the 5-10cm, relative to the 10-15cm depth. The 10-15cm subsurface level ranged in C:N from 4.2 (± 0.29 SE) (DC) to 13.6 (± 0.79 SE) (SB).

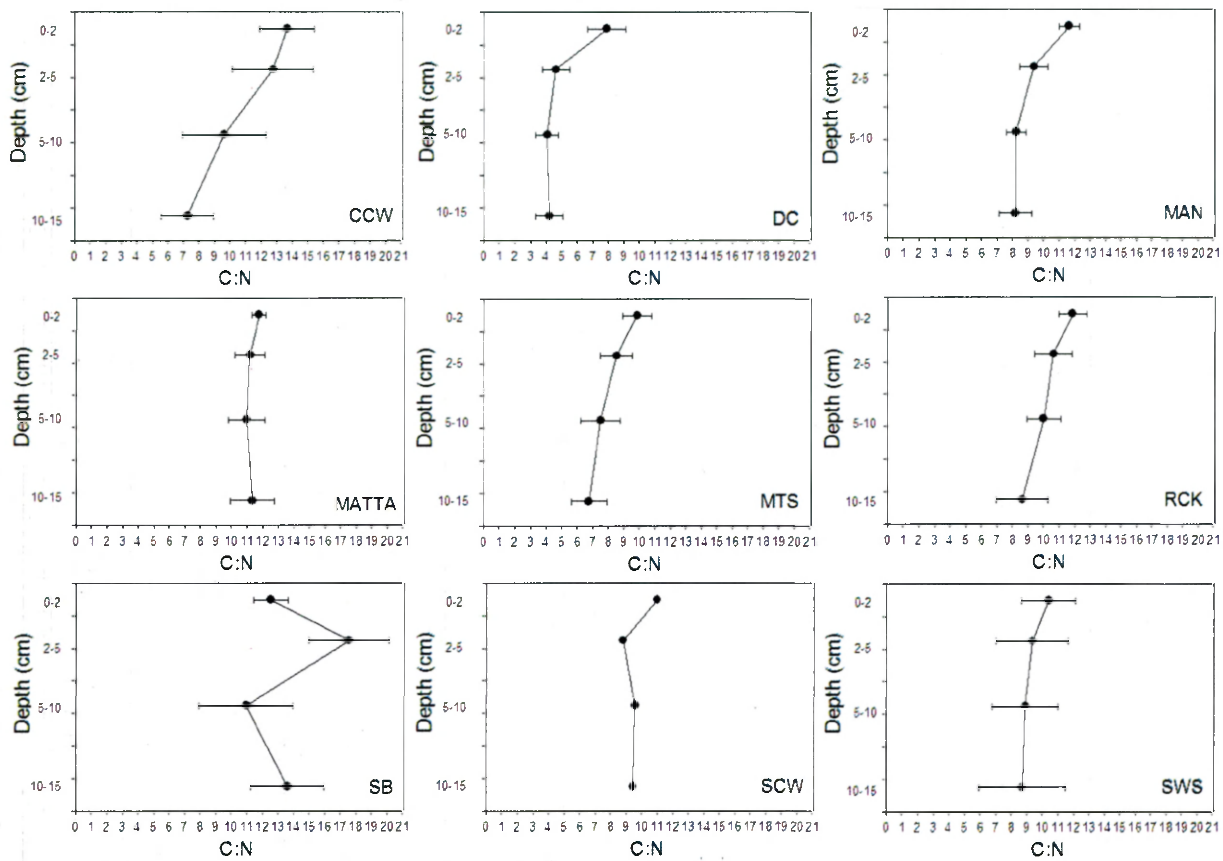

Figure 27a: C:N for all sites by depth from the surface.

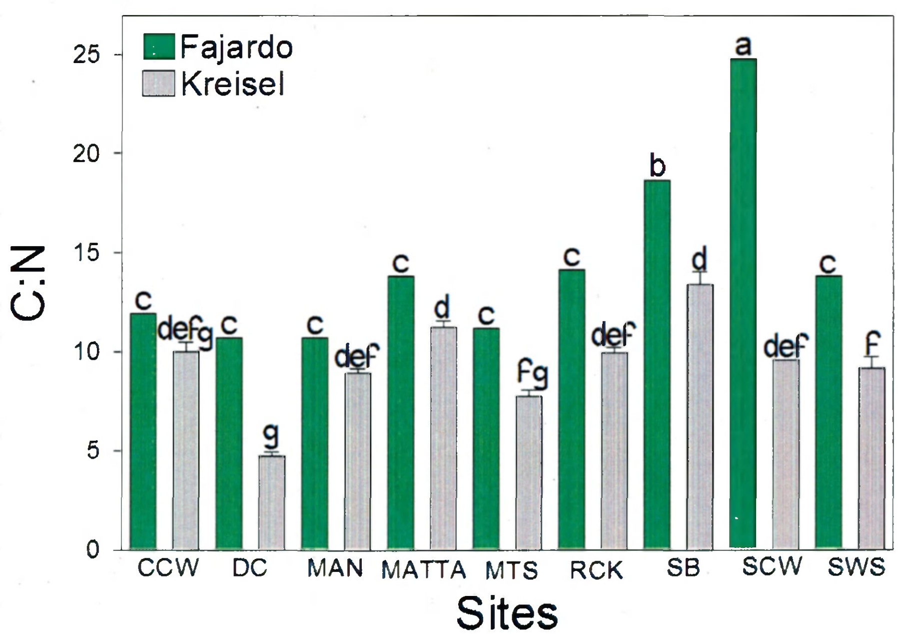

Figure 27b: Mean C:N + SE by study and site from 0-15cm. Different letters between bars indicate a significant difference within this study ($p < 0.05$). Significant differences existed between sites within Fajardo 2006 (a - c), within the current study (d - g) and between studies ($p < 0.008$).

3.2.4 Total Iron

Total iron concentrations ranged from 2,299 mg/kg (± 531 SE) (MATTA) to 18,848 mg/kg (± 1,142 SE) (MAN) with a mean of 7,619 mg/kg (± 645 SE). Generally, iron increases with depth, although this is not a significant trend (Figure 28a). Iron was only significantly higher at the surface 0-2cm layer at DC and SB with 5-10cm and 10-15cm, and at MATTA with 2-5cm (Appendix 5.7). The surface layer ranged in Fe concentrations from 2,388 mg/kg (± 204 SE) (MATTA) to 17,636 mg/kg (± 2,026 SE) (MAN). At the 2-5cm layer, MATTA, SB and SWS were significantly higher than the 10-15cm layer. SWS is the only site that was significant at the 5-10cm/10-15cm layer. The subsurface layer from 10-15cm ranged from 2,064 mg/kg (± 377 SE) (MATTA) to 20,400 mg/kg (± 1,671 SE) (MAN) in Fe concentrations.

For sites with high concentrations of iron greater than 1.5×10^4 mg/kg (MAN, RCK), variation within the sites was high (Figure 28a). Sites with lower iron concentration had less variation within the sites.

Soil iron varied significantly among nearly all of the sites ($p \leq 0.029$). The only comparisons that were not significant were between CCW and SWS ($p = 0.200$); SB and MATTA ($p = 0.886$) and MTS ($p = 0.200$); and then MATTA and MTS ($p = 0.114$) (Appendix 5.8.6).

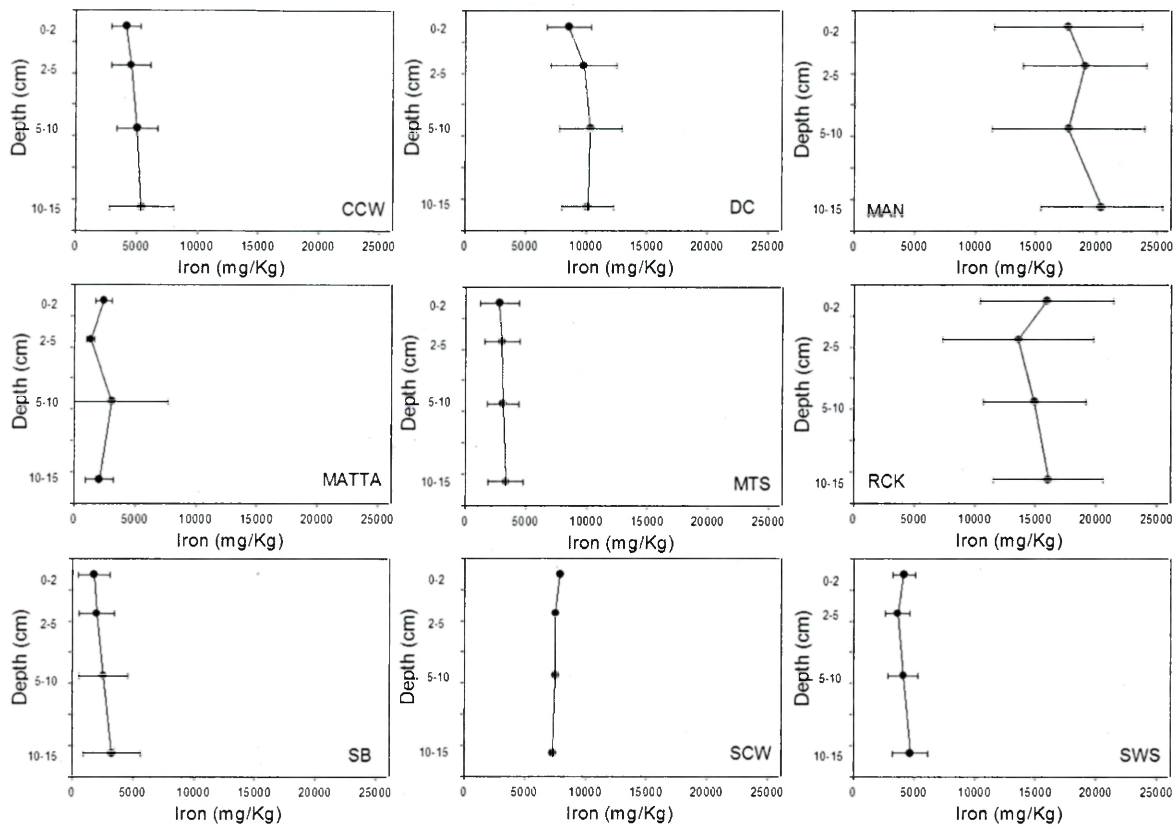

Figure 28a: Concentration of iron for all sites by depth from the surface.

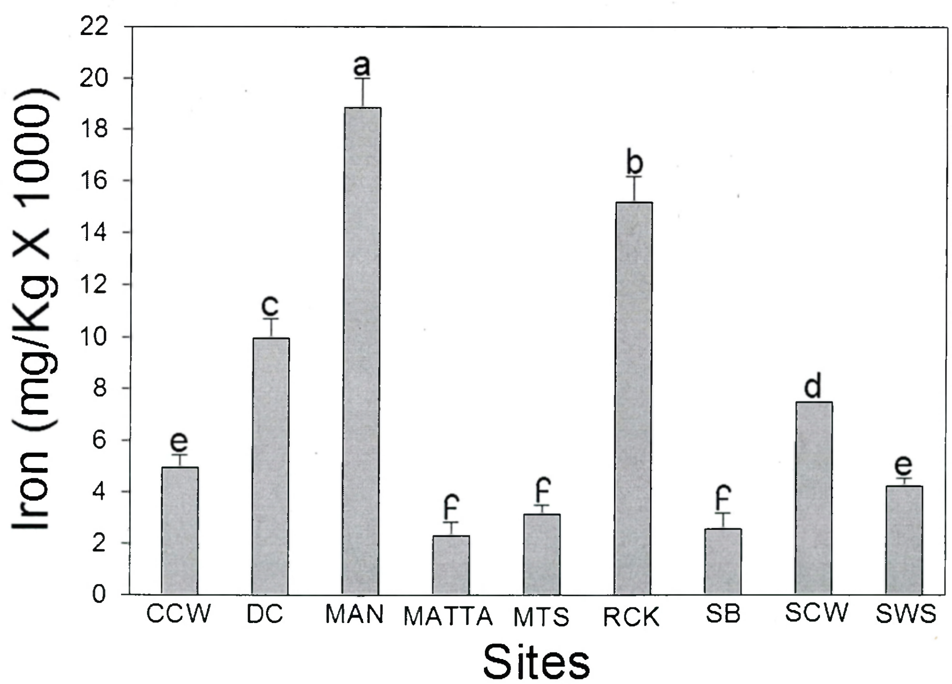

Figure 28b: Mean concentration of iron + SE for this study by site from 0-15cm. Different letters (a - f) between bars indicate a significant difference within this study ($p < 0.05$).

3.2.5 Total Phosphorus

Total phosphorus concentration ranged from 81.7 mg/kg (± 10.2 SE) (SB), to 204.7 mg/kg (± 4.2 SE) (MATTA). The mean for the study was 149.8 mg/kg (± 7.9 SE). P at SB was significantly lower than all other sites except CCW ($p \leq 0.029$). MAN was also significantly higher in P than DC, SCW, and SWS ($p \leq 0.029$) (Figure 29b, Appendix 5.8.7).

P concentration varied with depth at a majority of the sites (Figure 29a, Appendix 5.7). The 0-2cm surface layers of each of the sites contained significantly more P at each of the subsurface layers, ranging from 187.3 mg/kg (SCW*) to 294.5 mg/kg (± 15.5 SE) (MATTA). The 2-5cm layer was significantly higher at 5-10cm for CCW and SB, and at the 10-15cm layer for CCW, RCK, and SWS. The subsurface layer from 10-15cm ranged from 67.8 mg/kg (± 12.3 SE) (SB) to 187.5 mg/kg (± 6.4 SE) (MATTA).

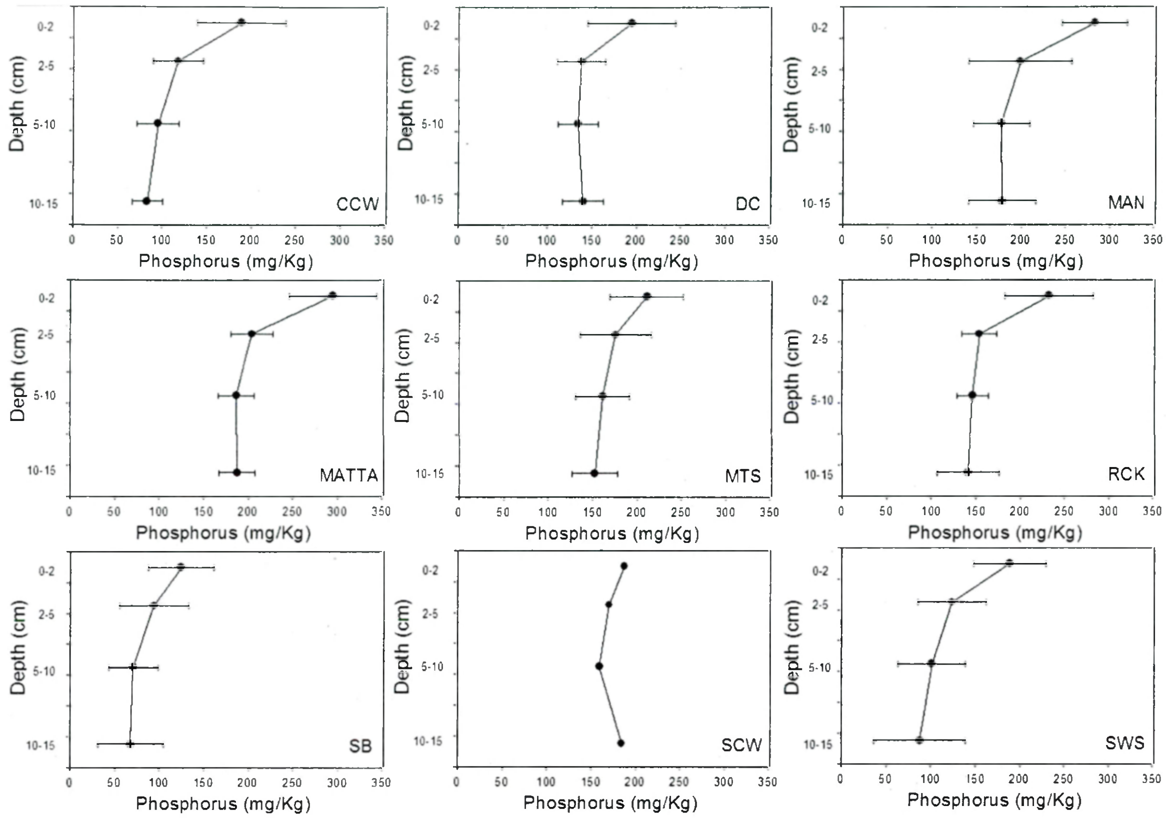

Figure 29a: Concentration of phosphorus for all sites by depth from the surface.

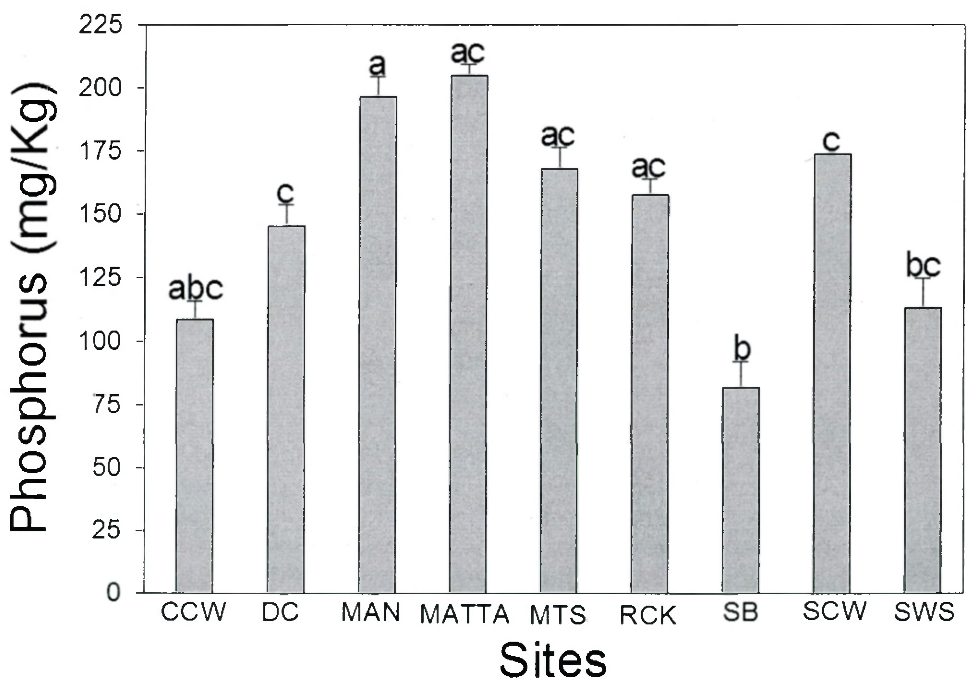

Figure 29b: Mean concentration of phosphorus + SE for this study by site from 0-15cm. Different letters (a - c) between bars indicate a significant difference within this study ($p < 0.05$).

3.3 *DISCUSSION*

Created wetlands tend to be characterized by low nutrient content, relative to natural reference sites. As mentioned in Chapter 2, created wetlands are most often plagued by improper hydrology, which in turn affects the aerobic status of the soil. This, in turn, affects the type of microbes that dominate the soil (whether aerobic or anaerobically dominated). Under proper anaerobic conditions supplemented with necessary OM, the microbial biomass can transform nutrients and allow them to accumulate in the soil solution. This nutrient accumulation is essential for the growth of vegetation, which in turn supplements OM for additional growth. Overall since Fajardo (2006), these sites accumulated significantly more N and C:N decreased significantly, and C accumulated at many sites. Nutrient accumulation may facilitate the growth of woody species and aid in the transformation of these sites to forested wetlands in the future.

3.3.1 Total Carbon

Soil carbon content is maintained in the same manner as organic matter: anaerobic conditions inhibit microbial biomass from breaking down the organic litter. Similarly, OM amendments serve as an "easy source" of food for the microbial biomass, allowing %C to accumulate in the soil surface. Total carbon, like soil OM, was highest in sites with more persistent flooding and suspected prolonged soil anoxia.

Like OM, relative age appears to have little effect on total carbon content amongst the sites. The top five sites for OM and %C were those that spanned the age range of created wetlands in this study. Of the five oldest sites, three did not receive organic amendments, whereas all of the the youngest four of the study did. The insignificant change in % C between studies ($p = 0.214$) may be due to the lack of time and age differentiation. These sites are all ≤ 10 years old, and with more time, these sites should show evidence of positive change (Anderson et al. 2005).

Within individual sites, total carbon content increased significantly between studies (Figure 24b, Appendix 5.7), perhaps due either to maturation of the site and/or to the increased length of time that the sites have spent inundated. Both the increase in site age, and length of time spent in anaerobic conditions could synergistically impact the level of total soil carbon.

Soil carbon content was lowest at SCW[1], even though soil sampling took place while the soil was flooded—conditions often associated with higher carbon content. The site was unsaturated in the beginning of the growing season, before the beaver dam became established. Once established, the dam held water during the middle of the field season and inundated the site. Even though the site spent half of the field season underwater, the soil had spent little time under these conditions before being sampled. The soil had already spent an unknown amount of time under aerating conditions, and additional soil carbon and OM may have been respired by microorganisms. There may not have been enough time spent inundated to replenish the spent % C.

In contrast, the high carbon content of SCW in the previous study can be explained by SCW having been one of the wettest sites sampled (Fajardo 2006). OM amendments were not equally spread across the site. The main body received much higher amendments than the eastern portion. The Fajardo study minimized this impact by averaging values for the site as a whole. Due to sampling constraints of deep water in this

[1] SCW could not be fully accounted for, due to missing data.
Hereafter, SCW* refers to having used a partial data set in the study.

study, only that eastern portion was sampled (SCW6). As a result, values of soil nutrients and characteristics in my study represent only a subset of the entire site. Relative to the Fajardo study, my results probably report % C soil values lower than actual average values for this site. Overall, the apparent variation exhibited between the studies also may be due to slight variation in combustion methods for ascertaining total %C.

In a relative ranking of sites for total carbon content, SB, like SCW is ranked much lower than in the Fajardo study. Further, MATTA and CCW now have greater %C than many of the other sites that previously had much higher C levels. Increased time of flooding may be responsible for this effect of increased %C retention, whereas the reverse may be true at SB, which may have become much drier since the previous study.

The %C content by depth varied within each of the individual sites (Figure 24a). The overall trend of these curves matched those pictured in Figure 22a, which illustrates the OM content by depth at each of the sites. Total C and OM measure related characters, so this relationship is expected and validates our findings. It also reconfirms the findings of Fajardo 2006, and further agrees with the literature (Cummings 1999; Stolt et al. 2001, Anderson et al. 2005) that generally % C decreases with depth.

3.3.2 Total Nitrogen

Nitrogen is an essential element for daily plant biochemical functions. Many studies report that total N levels are much higher in natural forested wetlands than in adjacent created forested wetlands which are correspondingly lacking (Cummings 1999; Stolt et al. 2000; Bruland et al. 2006). Fajardo reported concern for the lacking %N in the systems, hypothesizing that through further microbial decay, an increase in soil OM might increase soil nitrogen. This input could prevent both N deficiencies and productivity hindrances. As expected, both %OM, and %N have increased with time, and now there is significantly more %N in the current study ($p < 0.015$). This increase was apparent if not significant in nearly every site (Figure 25b). SCW* was the one exception.

Since there exists such a linkage between %N, %OM, and the microbial biomass, and OM (i.e. litter and roots) is concentrated in the surface layers, %N is concentrated in the surface as well (Nair et al. 2001). Looking in a deep (Fajardo 2006), moderate (Nair et al. 2001) and a shallower but more refined profile (the current study), it is evident that total N decreases with depth (Figure 25a).

Significant correlations existed between %OM, %N, % C, depth, and MSPD; whereby a decrease in the latter two results in an increase in the former three. There was an apparent relationship between the increased plant cover in this study and increased nitrogen in the study as a whole. This was evidenced by characteristics reported in this study such as increased species richness, landscape overviews, and greater ability to evaluate plots as hydrophytic where Fajardo (2006) was unable to evaluate.

Total Nitrogen Trajectory

These data (Figure 26) show that it may take the sites decades to accumulate the levels of total N equivalent to the natural reference sites (Nair et al. 2001). While Figures 26b and 26d show a linear progression of nutrient accumulation, I think that the accumulation will better resemble a logarithmic curve, with more significant accumulation in the first few decades, and then tapering off once the natural levels are approached. This is evidenced by the decreased slope from Fajardo 2006 to data from this study.

Figure 26 appears to show multiple stable states associated with the natural reference sites. The reference sites to the relatively dry created sites, especially MTS, RCK, SCW (before beaver activity) contained between 0.164% (MTS) to 0.360% (MAN) OM, and like for OM, were between 37 years old (MTS) and 79 years old (MAN) (DeBerry 2006). MTS has already reached its goal for N content, and the other three sites are relatively close. The reference sites to the relatively wet created sites, (CCW, MATTA, SWS) contained between 0.569 % (SWS) to 0.690% (CCW) N, and like for OM, were between 58 years old (MATTA) and 85 years old (SWS) (DeBerry 2006). The associated created sites may require decades to centuries to have the potential to become equivalent to the counterparts.

Only one site for which reference data were available has approached the level of % N equivalent to its reference site (MTS). There still is uncertainty as to whether the sites will reach the target values. Given this, I cannot fully predict if the sites will reach the levels of the natural counterparts; however, given the significant growth experienced since Fajardo 2006, should overall conditions at the sites remain the same, soil N should continue to increase (DeBerry 2006).

3.3.3 Carbon to Nitrogen Ratio (C:N)

As previously mentioned in Chapter 1, a C:N ratio around 15:1 to 20:1 is indicative of mature and stable soil OM (Nair et al. 2001). Maturing wetland soils also are characterized by an increase in both the quantity and quality of the OM, over time becoming more comparable to OM at natural sites (Nair et al. 2001).

The overall means for C:N amongst the sites have decreased significantly since last surveyed ($p < 0.008$), the range of which has decreased by nearly half (Figure 27b).

High ratios represent high C content and immobilized N whereas low ratios indicate net nitrogen mineralization by an active microbial biomass (Brady and Weil 2008). This process may be cause for concern near the soil surface (0-15cm), since these lower C:N ratios may favor N mineralization and further increase site nutrient availability (Nair et al. 2001), which may increase the potential for phytotoxicity due to excess available N and limited C. The low ratio indicates that there may be residual effects of soil ammonia retention (Fajardo 2006) or still an artifact of relatively low %C. Organic matter has been successfully broken down by an active microbial mass, but C:N has dipped below equivalent values for natural reference wetlands (Nair et al. 2001; Brady and Weil 2008). In my study, the constant influx of detritus from healthy plant cover appeared to be prevalent throughout the sites (Appendix 5.6).

Both %C and %N decreased with depth in my study, and C:N correspondingly decreased with depth (Figure 27a) . A similar pattern was documented by Fajardo (2006).

3.3.4 Total Iron

The iron extraction method used in this study (hydroxylamine hydrochloride) was more aggressive than the weak acid extraction employed in Fajardo (2006). As a result a comparison between studies is not possible. For my study, some sites were characterized by significantly more iron than other sites, namely MAN and RCK (Figure 28b). The presence of Triassic red soils at MAN may explain this significantly high concentration. Given the passage of time, sites may have seen a mild breakdown of soil particles and/or the direct breakdown of OM introduced into the system (Brady and Weil 2008) which may have generated more reactive iron. Also, hydroxylamine hydrochloride may reduce some of the oxidized soil Fe, contributing to a larger Fe extract (R. Chambers, pers.

comm.). Lastly, the variation in concentration among sites may have arisen due to sulfidic materials and a change in pH as Fajardo (2006) previously reported. However, these characteristics were not measured, and so no further conclusion can be reached.

Neubauer (et al. 2007) reported that a favorable environment and high densities of iron-oxidizing bacteria may contribute to the formation of more iron plaques, "rust-colored precipitates" (Weiss et al. 2003), on the rhizosphere. The microbial community is adequately developed and active and may include more iron-oxidizing bacteria (FeOB) that are able to hold more Fe in the surface layers of the soil (Figure 28a). The relatively large amount of overall plant cover (Chapter 2) and rise in soil %OM (Chapter 2) (Brady and Weil 2008) can provide OM for microbial breakdown via Fe reduction. Alternately, the increased amount of root area from more plants may create oxidized zones FeOB. Neubauer et al. (2007) reports that these bacteria may be able to increase that rate of Fe oxidation consequently allowing for increased Fe precipitation.

I did not find a relationship between higher Fe content and the direction the plots are taking towards becoming more oxidized or reduced. However, sites that have a majority of their plots becoming more reduced over time (DC, MAN, MATTA, SCW*) tend to contain the most Fe (MAN, RCK, DC, SCW*). Correspondingly, these sites were also some of the wettest of the study. Since Fe was measured from the soil solution it may be possible to conclude that sites with more prolonged flooding tend to contain more Fe.

3.3.5 Total Phosphorus

The sampling method utilized in this study was more aggressive than one that would look at just plant available nutrients, which was the method employed in Fajardo (2006). As a result a comparison between studies is not possible.

Normal levels of wetland soil P typically range from about 0.01% to 0.2% (R. Chambers, pers. comm.), and I found values on the low end of that scale (Figure 29b). The fact that P levels are within the intended range indicates that P levels have reached equivalency with mature sites.

Nair et al. (2001) noted increases in available P in created sites. On the other hand, DeBerry (2006) found that soil P held a negative correlation with species richness. Given this, I might be led to hypothesize that in fact, regardless of these sufficient levels of P, the increase in species richness exhibited in the sites (Chapter 2) may indicate that, in fact, the sites exhibited a decrease in soil P. Further analysis to compare data from this study to Fajardo (2006) is necessary to draw this conclusion.

A variety of factors could explain the increase in soil P concentration between studies. The increase of %OM, and overall plant cover discussed in Chapter 2 most likely contributed to the increase in P from active soil OM by being released from the detritus by the microbial biomass. Alternately, these data show that most of the sites with high concentrations of Fe had similarly larger concentrations of P. Since Fe has an affinity for P in the soil solution, and Fe precipitates primarily in the rhizosphere when oxidized (Mitsch and Gosselink 2000), the large amount of P may be directly related to the increase in Fe discussed earlier.

Similar to iron, higher phosphorus content does not appear to be related to soil redox status (i.e., oxidized or reduced). However, a general trend is that sites with a majority of plots becoming more reduced over time (DC, MAN, MATTA, SCW*) contain the most P (MATTA, MAN, MTS, SCW*). These sites were also some of the wettest of the study. Mitsch and Goesslink (2000) comment on availability of P (to flora) tending to increase in waterlogged soils, and coinciding with the overall increase in %OM. The exception is that P precipitates out with iron. Since P was measured from the soil solution I may conclude that sites with more extensive flooding tend to contain more P.

Additionally, every one of these sites is relatively close to farm or residential neighborhoods. As an external source, P may have leached from fertilizers used in the area to these downstream wetland sinks.

3.4 *CONCLUSIONS*

In summary, soil nutrient concentrations appear to be increasing over time, and while it remains to be seen if the sites will acquire values consistent with those seen in natural reference sites, many do appear to be on a trajectory of growth towards those natural site values. Soil C has increased since Fajardo (2006), while N significantly increased and C:N significantly decreased. In creating new forested wetland sites, an organic amendment with a C:N close to the desired final ratio (approximately 20:1) should help boost microbial activity and concomitantly increase soil nutrient levels.

Continued monitoring of these sites approximately every five years is crucial to developing a baseline data set of developmental characteristics of these sites. Additionally, a prompt return to SCW after removing the beaver dam would complete the data set. Further investigation to compare acid extractable P and Fe to values in Fajardo (2006) will help to complete the picture as to the nutrient change over time.

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5. Appendices

5.1 Wetland Photos Fajardo (2006) versus the current study

5.1.1 Charles City

Figure 30a: Southwest view of CCW near sample location 1 (April 2002).

Figure 30b: Southwest view of CCW near sample location 1 (September 2008).

Figure 30c: Northern view of CCW near sample location 4 (April 2002).

Figure 30d: Northern view of CCW near sample location 4 (September 2008).

5.1.2 Dick Cross

Figure 31a: Northern view of DC from sample location 6 (August 2002).

Figure 31b: North- Northwestern view of DC from sample location 6 (September 2008).

Figure 31c: Southern view of DC from sample location 10 (August 2002).

Figure 31d: Southern view of DC from sample location 10 (September 2008).

5.1.3 Manassas

Figure 32a: Eastern view of MAN near sample location 3 (July 2002).

Figure 32b: Eastern view of MAN near sample location 3 (September 2008).

Figure 32c: Southern view of MAN near sample location 8 (July 2002).

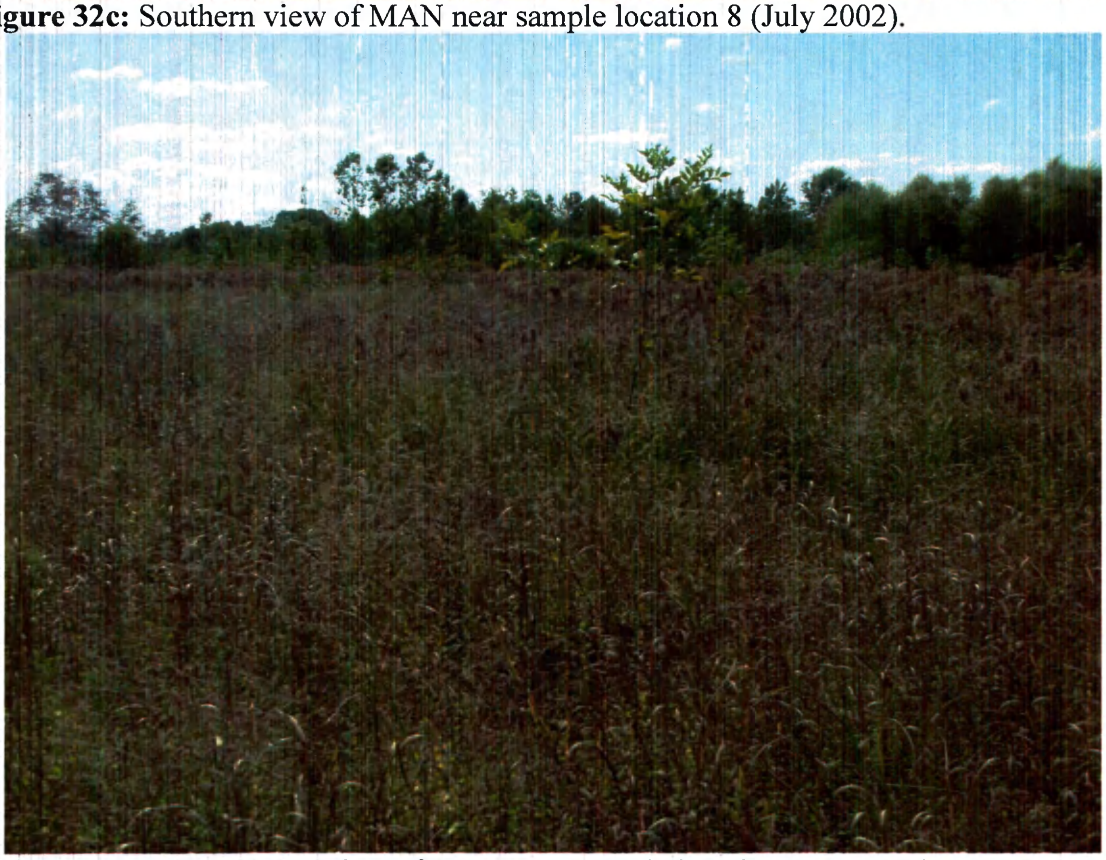

Figure 32d: Southwestern view of MAN near sample location 8 (September 2008).

5.1.4 Mattaponi

Figure 33a: Western view of MATTA near sample location 4 (May 2002).

Figure 33b: Western view of MATTA near sample location 4 (September 2008).

Figure 33c: Northern view of MATTA near sample location 7 (May 2002).

Figure 33d: Northern view of MATTA near sample location 7 (September 2008).

5.1.5 Mount Stirling

Figure 34a: Northern view of MTS near sample location 3 (October 2003).

Figure 34b: Northern view of MTS near sample location 3 (September 2008).

Figure 34c: Southeastern view of MTS near sample location 9 (October 2003).

Figure 34d: Southeastern view of MTS near sample location 9 (September 2008).

5.1.6 Reedy Creek

Figure 35a: Northern view of Section B at RCK near sample location 11 (March 2004).

Figure 35b: Northern view of Section B at RCK near sample location 11 (September 2008).

Figure 35c: Southern view of Section C at RCK near sample location 6 (March 2004).

Figure 35d: Southern view of Section C at RCK near sample location 6 (September 2008).

5.1.7 Sandy Bottom

Figure 36a: Northeastern view section of SB near sample location 4 (August 2003).

Figure 36b: Northern view of SB near sample location 4 (September 2008).

Figure 36c: View of southeastern portion of SB near sample location 3 (August 2003).

Figure 36d: Western view of SB near sample location 3 (September 2008).

5.1.8 Stony Creek

Figure 37a: Southern view of SCW near sample location 3 (July 2002).

Figure 37b: Southwestern view of SCW near sample location 3 (September 2008).

5.1.9 SW Suffolk/ Lake Kilby

Figure 38a: Northern view of SWS near sample location 9 (April 2004).

Figure 38b: Northeastern view of SWS near sample location 9 (September 2008).

Figure 38c: Eastern view of SWS near sample location 5 (April 2004).

Figure 38d: Eastern view of SWS near sample location 5 (September 2008).

5.2 Directions to Field Sites (in U.S. Customary Units)

The field vehicle was a short four-door sedan. As a result, I can safely say that any future field vehicle, with a careful driver, can safely navigate the off-road roads to these mitigation sites.

5.2.1 Charles City

1. This site can only be accessed by entering from private property: the Clada Farms. The property owners welcome researchers; however it is imperative that the future researcher contact the owners, if for no other reason than to find out the proper place to park, so that the researcher's vehicle doesn't get damaged by farm vehicles.
2. From Williamsburg VA: Take Route 5 (John Tyler Memorial Highway) going west for 12.2 miles from Route 199/Route 5, make a right onto Wilcox Neck Road. Drive for 3.9 miles; on the left hand side is the sign, and entrance to the Clada Farms.
3. I-64 exit 214 to Route 155 (North Courthouse Road). Take this South for 4.2 miles. Keep right to stay on Route 155 (South Courthouse Road) for another 2.1 miles. Turn left onto Sturgeon Point Road (3.2 miles), left onto The Glebe Road (5.2 miles), and right onto Wilcox Neck Road. 1.3 miles up the road on the right will be a sign, and entrance to the Clada Farms.

5.2.2 Dick Cross

1. From the road, it is 1-2 miles to the mitigation site, so driving to the site off of the main road is highly recommended.
2. I-85 to exit 12B (Route 58 / W East Atlantic St), towards South Hill VA. Take Route 58 west until the intersection with Baskerville Road (9.7 miles). Baskerville Road ends in a "T" with Redlawn Road (2.5 miles). Make a right onto Redlawn Road. Follow it until you pass the house address 5592 Redlawn Road (1.5 miles). There will be a sign right after for "Dick Cross Wildlife Management Area" the identifying marker for the site (Figure 39).

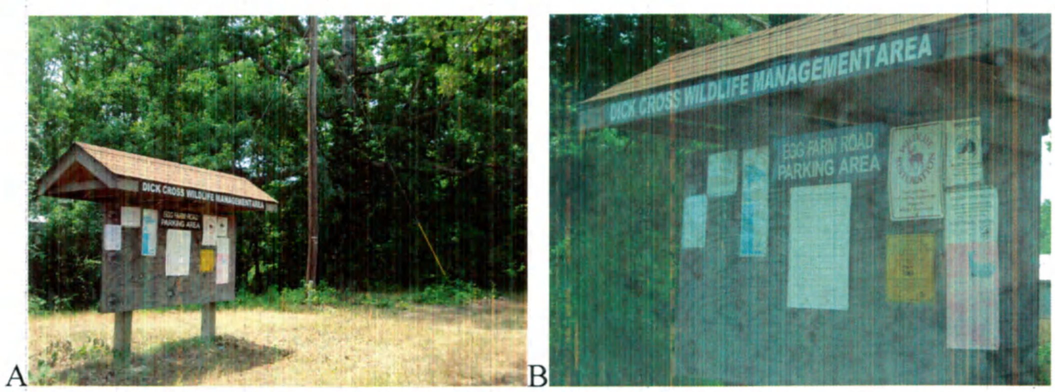

Figure 39: Entrance markers to Dick Cross.

3. I advise the researcher to approach the site from the angle of the picture showing the telephone pole, as the ground is uneven elsewhere (front left). In order to enter

the site, the researcher must drive to the right of the pictured telephone pole, between the yellow sheath and wood pole. There is a slight hill to drive down, around 100 feet of forest to drive through, and then the researcher should turn left at the break in the forest. There is then 1-2 miles to drive through before finally approaching the wetland.

4. It is easiest to drive into the site during the spring, early summer, and winter, as someone keeps it well mowed. There is an exceptional amount of vegetation that grows in the road, and makes it difficult to drive through the site by late summer.

5.2.3 Manassas

1. This gate of the site is around 150 feet from the main road. It can be accessed either by parking outside the gate, or by contacting a member of VDOT to obtain the combination to the lock on the gate. The site begins shortly after the gate, so obtaining the combination is not essential.
2. I-95 to exit 152 B (from I95 North), to Route 234 North (Dumfries Rd) toward Manassas (16.1 mi).
3. Take a left on Clover Hill Road which becomes Harry J. Parrish Blvd when it turns. After 600 yards there will be a building on the right, and a dirt road going downhill on the left. The gate at the head of the site will be far but visible from the road.

5.2.4 Mattaponi

1. The entrance to the site is right off of the road, the researcher can park right outside of the gate to the site.
2. I-95 exit 104 towards Bowling Green (NE) puts the researcher onto Route 207 (Rogers Clark Boulevard). Make a right onto Nelson Hill Road (7.2 miles). Follow this road until the road curves to the right (1.9 miles). Nelson Hill Road splits at this curve. Going right takes you over a bridge and the CSX railroad. The researcher wants to go left down a short road, the sign of which is also labeled as Nelson Hill Road. It is around 100-200 feet long. There will be a gate on the left-hand side; this is the entrance to the mitigation wetland.

5.2.5 Mt. Stirling

1. This site can only be accessed by entering from private property: Mt. Stirling Farm. To enter this site, the consulting company that created this site -the Williamsburg Environmental Group (WEG) needs to be contacted for permission (they will contact the landowners).
2. I-64 exit 214 to Route 155 (North Courthouse Road). Take this South for 4.2 miles. Keep right to stay on Route 155 (South Courthouse Road) for another 1.5 miles until reaching Mt. Stirling Farm Road. This road is on the private farm property.

5.2.6 Reedy Creek

1. This site can only be accessed by entering from private property. To enter this site, the consulting company that created this site - the Williamsburg Environmental Group (WEG) needs to be contacted for permission. It is also

essential to acquire the combination to the lock on the gate at the road. From the main road, it is ~ 2 miles to Section C, the farthest section, but plots from Section B (the closest to the main road) still lie more than a mile into the property. Driving off of the main road to the site is highly recommended.

2. I-95 to Route 288 North (WWII Vets Highway) at exit 62 for 13.3 miles. Take US-360 West (Hull St Rd) towards Amelia for 3 miles. Turn left on Winterpock Road for 5.7 miles, left on Black Road for 1 mile, and right on River Road for 3.2 miles.
3. The gate to this site will be very unassuming, ~15 yards off from the main road. (Reaching a fork from the main road (a dirt road) means the researcher has driven ~500 yards too far.)
4. The dirt road to the site can be hard to navigate due to excessive potholes, on the relatively narrow road. Felled trees occasionally cover driving paths. A GPS is essential merely to navigate forks in the roads to enter the mitigation site.
5. A very large tree (1 yard width) covers the entire path to Section C (farthest from the main road). It must be climbed over to enter the site. A small step stool might prove beneficial, although strong branches aid in crossing as well.

5.2.8 *Sandy Bottom*

1. This site is within a public park. Inform the rangers or visitor center of your presence to do work each day after gaining permission from the main administrator. The rangers are also helpful for pointing out the mitigation site since it is located within a large park.
2. I-64 exit 261A to Big Bethel Road (0.5 miles). Continue on Big Bethel for 0.3 miles. A sign for Sandy Bottom Nature Park is on the left, turn here to enter the park. Parking is possible in the main lots for the park.

5.2.8 Stony Creek

1. The site is extremely accessible located only feet from the main road.
2. I-95 exit 31 to Route 40. Make a left onto Route 40 (East). Go 0.6 miles, the site is located on the left-hand side. It is the next left after Route 317 (Red Bank Road).

5.2.9 SW Suffolk/ Mt. Kilby

1. This site lies right behind a residential neighborhood.
2. I-64 exit 264 to I-664 (Hampton Roads Beltway) South for 18.8 miles. I-664 exit 13A to US-13 South / US-58 West / US-460 West / W Military Hwy toward Suffolk, VA for 14.5 miles. Turn left onto US-58 Business (Holland Road), and then keep right to stay on that road. Turn right on Kilby Shores Drive (70 yards). Drive on Kilby Shores Drive for 0.8 miles.
3. Parking by 519 Kilby Shores Drive allows access without trespassing to SWS 6 – SWS 10. Parking by 519 Canine Trail in the cul-de-sac allows access without trespassing to SWS 1 – SWS 5. Canine Trail can be accessed by continuing on Kilby Shores Drive for 0.2 miles and turning right.

Directions obtained from TomTomOne and verified from MSN Live Search Maps.

5.3 Recorded Vascular Plant Species

Acer negundo (Box Elder) Study number 147; Herbarium number SK119
*Acer rubrum (*Red Maple) Study number 25; Herbarium number NA
Agalinis purpurea (purple false foxglove) Study number 183;
Herbarium number SK79, SK86
Albizia julibrissin (Silktree/Mimosa) Study number 97; Herbarium number SK47, SK90
Alisma subcordatum (American water plantain) Study number 24;
Herbarium number SK106
Ambrosia artemisiifolia (ragweed) Study number 199; Herbarium number SK68
Ammannia auriculata (valley redstem) Study number 196; Herbarium number SK19
Andropogon virginicus (broomsedge bluestem) Study number 33, 110;
Herbarium number SK32
Apocynum cannabinum Study number 69; Herbarium number SK63
Aster novae-angliae Study number 188; Herbarium number
Aster sp. (aster) Study number 162; Herbarium number NA
Aster vimineus Study number 8, 144; Herbarium number NA
Baccharis halimifolia (eastern baccharis, groundsel tree) Study number 71;
Herbarium number SK23
*Betula nigra (*River Birch*)* Study number 68, 131; Herbarium number NA
Bidens comosa now *Bidens tripartita,* this info for comosa, see USDA for other
Study number 141, 192, 194; Herbarium number SK8, SK34, SK96
Bidens discoidea Study number 189; Herbarium number SK24
Bidens frondosa Study number 1; Herbarium number SK75
*Bidens sp.*Study number 23; Herbarium number NA
Boehmeria cylindrica Study number 202; Herbarium number SK82
Carex crinita Study number 87; Herbarium number SK2
Carex echinata (star sedge) Study number 124; Herbarium number NA
Carex extensa (longbract sedge) Study number 138; Herbarium number SK97
Carex lurida (shallow sedge) Study number 56, 155;
Herbarium number SK25, SK41, SK52
Carex suberecta Study number 16; Herbarium number SK53
Carex vulpinoidea (fox sedge) Study number 19; Herbarium number SK121
Cephalanthus occidentalis (common buttonbush) Study number 100;
Herbarium number SK114
*Chasmanthium sp.*Study number 161; Herbarium number NA
Conoclinium coelestinum (blue mistflower) Study number 42; Herbarium number NA
Cornus florida (Dogwood) Study number 65; Herbarium number NA
Cuscuta pentagona (fiveangled dodder) Study number 133;
Herbarium number SK13, SK14
Cyperacae (sedges) Study number 152; Herbarium number SK27
Cyperus echinatus (globe flatsedge) Study number 122; Herbarium number SK33
Cyperus esculentus Study number 168; Herbarium number SK1
Cyperus iria Study number 195; Herbarium number SK7
Cyperus strigosus (strawcolored flatsedge) Study number 165;
Herbarium number SK21, SK29
Decodon verticillatus (swamp loosestrife) Study number 130; Herbarium number NA
Digitaria sanguinalis Study number 201; Herbarium number SK37
Diodia virginiana (Virginia buttonweed) Study number 58, 127; Herbarium number NA

Diospyros virginiana (common persimmon) Study number 96; Herbarium number NA
Dulichium arundinaceum (threeway sedge) Study number 153;
Herbarium number SK107
Echinochloa muricata (rough barnyardgrass) Study number 143, 163;
Herbarium number SK73, SK112
Eclipta prostrata (false daisy) Study number 164; Herbarium number SK40, SK66
Eleocharis acicularis (needle spikerush) Study number 103;
Herbarium number SK55, SK100
Eleocharis obtusa (blunt spikerush) Study number 2; Herbarium number NA
Eleocharis quadrangulata (squarestem spikerush) Study number 102;
Herbarium number SK98
Epilobium angustifolium (Chamerion angustifolium) (fireweed) Study number 44;
Herbarium number NA
Epilobium coloratum Study number 184; Herbarium number SK59
Epilobium parviflorum Study number 177; Herbarium number NA
Erianthus giganteus Study number 55; Herbarium number NA
Erigeron annuus Study number 31; Herbarium number NA
Eupatorium capillifolium Study number 64; Herbarium number SK64, SK91
Eupatorium serotinum (lateflowering thoroughwort) Study number 145;
Herbarium number SK22, SK111
*Euthamia sp.*Study number 82; Herbarium number NA
Euthamia tenuifolia (Euthamia caroliniana) (slender goldentop) Study number 132;
Herbarium number NA
Festuca rubra (red fescue) Study number 107; Herbarium number NA
Fraxinus pennsylvanica (green ash) Study number 111, 136; Herbarium number NA
Galium tinctorium Study number 36; Herbarium number NA
Graminoid (grass family) Study number 40; Herbarium number NA
Gratiola aurea Study number 109; Herbarium number NA
Hydrocotyle bonariensis (largeleaf pennywort) Study number 90; Herbarium number NA
Hydrocotyle ranunculoides (floating marshpennywort) Study number 148;
Herbarium number SK39
Hydrolea quadrivalvis (waterpod) Study number 28; Herbarium number NA
Hypericum mutilum Study number 43; Herbarium number SK9
Hypericum stans (St. John's Wort) Study number 48; Herbarium number NA
Ilex opaca (American holly) Study number 95; Herbarium number NA
Ilex verticillata Study number 175; Herbarium number SK3
Impatiens capensis (jewelweed) Study number 66, 185; Herbarium number SK65
Ipomoea coccinea (morning glory) Study number 169; Herbarium number SK6
Juncus acuminatus (tapertip rush) Study number 6; Herbarium number SK56
Juncus effusus (common rush) Study number 11, 14; Herbarium number SK57
Leersia oryzoides (rice cutgrass) Study number 7, 80; Herbarium number SK54, SK88
Leersia virginica (whitegrass) Study number 151; Herbarium number SK42
Lemna perpusilla (minute duckweed) Study number 149; Herbarium number SK117
Lespedeza bicolor Study number 117; Herbarium number SK18
Lespedeza capitata Study number 83; Herbarium number SK58
Lespedeza cuneata Study number 32, 37; Herbarium number SK81
Lindernia dubia (yellowseed false pimpernel) Study number 142;
Herbarium number SK7
Liquidambar styraciflua (sweetgum) Study number 35; Herbarium number NA

Lolium arundinaceum (tall fescue) AKA Schedonorous phoenix Study number 70, 75;
Herbarium number SK49
Lonicera japonica (honeysuckle) Study number 38, 45, 49, 99;
Herbarium number SK84, SK115
Ludwigia alternifolia Study number 22, 139; Herbarium number SK122
Ludwigia alternifolia (seedbox) Study number 9; Herbarium number NA
Ludwigia palustris Study number 3; Herbarium number NA
*Lycopus sp.*Study number 160; Herbarium number NA
Lycopus virginicus Study number 112, 172, 187; Herbarium number SK20, SK72
Lysimachia nummularia (creeping jenny) Study number 121; Herbarium number NA
Melothria pendula (creeping cucumber) Study number 98;
Herbarium number SK87, SK113
Microstegium vimineum (Nepalese browntop/ Japanese stiltgrass) Study number 60;
Herbarium number SK43, SK44
*Mikania scandens (*Hemp Vine) Study number 92; Herbarium number SK15, SK74
Morella surifera Study number 198; Herbarium number SK62
Murdannia keisak (day lily) Study number 171, 176;
Herbarium number SK69, SK70, SK85
Nyssa sylvatica (blackgum) Study number 134; Herbarium number NA
Oenothera glazioviana Study number 120, 174; Herbarium number NA
Oxalis europaea Study number 125; Herbarium number NA
Panicum clandestinum (Dichanthelium clandestinum) (deertongue) Study number 47, 94;
Herbarium number SK16
Panicum dichotomiflorum Study number 167; Herbarium number SK4
Panicum rigidulum Study number 197; Herbarium number SK30
Panicum scoparium (Dichanthelium scoparium) Study number 84, 116, 173;
Herbarium number SK38
Panicum sp Study number 15, 54, 79, 106, 170; Herbarium number NA
Panicum texanum (Urochloa texana) (Texas signalgrass) Study number 166;
Herbarium number SK26
Parthenocissus quinquefolia Study number 51; Herbarium number NA
Paspalum boscianum (bull crowngrass) Study number 104; Herbarium number SK99
Phleum pratense (Timothy Grass) Study number 86; Herbarium number SK93
Phragmites australis (common reed) Study number 105; Herbarium number NA
Phyllanthus caroliniensis Study number 182; Herbarium number SK12
Pilea fontana (lesser clearweed) Study number 29; Herbarium number NA
Pinus taeda (Loblolly Pine) Study number 61; Herbarium number NA
Platanus occidentalis (sycamore) Study number 119; Herbarium number NA
Pluchea odorata (sweetscent) Study number 159; Herbarium number SK11
Polygonum hydropiperoides Study number 5; Herbarium number SK103, SK105
Polygonum pensylvanicum (Pennsylvania smartweed) Study number 157;
Herbarium number NA
Polygonum sagittatum Study number 53; Herbarium number SK60
Polystichum acrostichoides (christmas fern) Study number 186; Herbarium number NA
Potentilla sp. Study number 115; Herbarium number NA
Ptilimnium capillaceum Study number 89; Herbarium number SK94
Quercus bicolor Study number 190; Herbarium number SK35
Quercus laurifolia (laurel oak) Study number 26, 129; Herbarium number NA
*Quercus palustrus (*pin-oak) Study number 57; Herbarium number NA

Quercus phellos (willow oak) Study number 140; Herbarium number SK118
Ranunculus sardous (buttercup) Study number 73; Herbarium number SK28
Rhexia mariana Study number 50, 181; Herbarium number SK61
Rhynchospora corniculata (shortbristle horned beaksedge) Study number 178; Herbarium number SK77
Rorippa sylvestris (creeping yellowcress) Study number 150; Herbarium number SK116
Rosa palustris Study number 91; Herbarium number SK104
Rubus allegheniensis Study number 30; Herbarium number SK101
Rumex crispus (curly dock) Study number 72, 88; Herbarium number SK48, SK51
Rumex verticillatus (swamp dock) Study number 154; Herbarium number SK108
Salix Nigra (black willow) Study number 101, 135; Herbarium number SK80, SK110
Saururus cernuus (lizard's tail) Study number 21; Herbarium number NA
Scirpus atrovirens (green bulrush) Study number 4, 128; Herbarium number NA
Scirpus cyperinus (wool geass) Study number 10; Herbarium number SK83, SK102
Scirpus validus (*Schoenoplectus tabernaemontani)* (softstem bulrush) Study number 146; Herbarium number SK36
Scrophularia sp. (figwort) Study number 158; Herbarium number NA
Scutellaria integrifolia Study number 39; Herbarium number NA
Selaginella apoda Study number 67; Herbarium number *NA*
Setaria glauca Study number 108, 191; Herbarium number SK31
Setaria parviflora Study number 179; Herbarium number SK78
Solanum carolinense (Carolina horsenettle) Study number 156; Herbarium number SK109, SK120
Solidago canadensis Study number 13, 34; Herbarium number SK5
*Solidago sp.*Study number 12, 18, 74; Herbarium number NA
Solidago uliginosa (bog goldenrod) Study number 93; Herbarium number NA
Sorghum halepense (johnson grass) Study number 20, 85; Herbarium number NA
Sparganium americanum (American burr reed) Study number 77; Herbarium number SK50
Spiraea tomentosa (steeplebush) Study number 123; Herbarium number SK92
Taxodium distichum Study number 59; Herbarium number SK76, SK89
Teucrium canadense Study number 41; Herbarium number NA
Toxicodendron radicans (eastern poison ivy) Study number 46; Herbarium number NA
Trifolium hybridum (alsike clover) Study number 81; Herbarium number SK45
Typha latifolia (broadleaf cattail) Study number 78; Herbarium number SK71
Ulmus rubra (slippery elm) Study number 62; Herbarium number NA
"Unknown" Study numbers 113, 126; Herbarium number NA
Vernonia noveboracensis (New York ironweed) Study number 52, 118, 137, 180; Herbarium number SK67, SK95
Viburnum dentatum (arrowwood) Study number 63; Herbarium number NA
Vicia cracca Study number 76; Herbarium number SK17
Xanthium strumarium Study number 193; Herbarium number SK46

5.4 Dominant Species

5.4.1 Dominant species in each study by site.

Table 17: Dominant species in each study by site. Species in Fajardo are listed in alphabetical order: hydrophytes and then non-wetland plants (separation indicated by underline). Species in Kreisel are listed in order of decreasing dominance.

	FAJARDO 2006 (sampling 2002-2004)	KREISEL (sampling 2008)	# Δ Dom
CCW	*Juncus acuminatus* *Juncus effusus* *Juncus tenuis* *Scirpus cyperinus* *Ambrosia artemisiifolia* *Solidago speciosa*	*Scirpus cyperinus* *Juncus effusus,* *Bidens frondosa,* *Solidago canadensis,* *Juncus acuminatus,* *Ludwigia palustris*	+3 -3 **0**
DC	*Eleocharis obtusa* *Juncus effusus* *Juncus tenuis* *Paspalum floridanum* *Typha latifolia* *Lespedeza cuneata* *Panicum ancepts*	*Juncus effusus,* *Scirpus cyperinus,* *Ludwigia palustris,* *Juncus acuminatus,* *Panicum scoparium* *Panicum clandestinum* *Galium tinctorium*	+6 -6 **0**
MAN	*Bidens frondosa* *Juncus acuminatus* *Juncus tenuis* *Lindernia dubia* *Ludwigia palustris* *Scirpus cyperinus* *Typha angustifolia* *Typha latifolia* *Panicum ancepts*	*Ludwigia palustris,* *Scirpus cyperinus,* *Microstegium vimineum,* *Juncus effusus,* *Typha latifolia,* *Aster novae-angliae,* *Juncus acuminatus,* *Alisma subcordatum,* *Polygonum hydropiperoides*	+5 -5 **0**
MATTA	*Juncus effusus* *Lemna valdiviana* *Typha latifolia*	*Juncus effusus* *Echinochloa muricata* *Ludwigia palustris* *Polygonum hydropiperoides*	+3 -2 **+1**
MTS	*Juncus effusus* *Lemna valdiviana* *Typha latifolia*	*Juncus effusus* *Polygonum hydropiperoides* *Diodia virginiana* *Lonicera japonica* *Microstegium vimineum* *Ludwigia palustris* *Acer rubrum* *Conoclinium coelestinum* *Solidago Canadensis*	+8 -2 **+6**

Table 17 continued

	FAJARDO 2006 (sampling 2002-2004)	KREISEL et al. (sampling 2008)	# Δ Dom
RCK	*Alisma subcordatum* *Carex vulpinoides* *Echinochloa walteri* *Eleocharis obtusa* *Juncus effusus* *Ludwigia decurrens* *Ludwigia palustris* *Polygonum pensylvanicum* *Scirpus atrivirens* *Typha latifolia*	*Lespedeza cuneata* *Andropgon virginicus* *Juncus effusus* *Aster vimineus* *Panicum scoparium* *Juncus acuminatus* *Panicum sp.* *Solidago sp.* *Lycopus virginicus*	+8 -9 **-1**
SB	*Aster noveanglii* *Betula nigra* *Carex vulpinoides* *Diodia virginiana* *Eleocharis obtusa* <u>*Typha latifolia*</u> *Ambrosia artemisiifolia* *Eupatorium capillifolium* *Lolium perenne* *Vicia sativa*	*Lespedeza cuneata* *Juncus effusus* *Panicum dichotomiflorum* *Setaria glauca* *Polygonum hydropiperoides* *Panicum sp.*	+6 -10 **-4**
SCW	*Echinochloa crus-galli* *Eleocharis obtusa* *Salix nigra*	*Juncus effusus,* *Polygonum hydropiperoides,* *Scirpus cyperinus,* *Ludwigia palustris*	+4 -3 **+1**
SWS	*Agrostis stolonifera* *Juncus effusus* <u>*Typha latifolia*</u> *Eragrostis pilosa* *Lolium perenne* *Trifolium pratensis*	*Juncus effusus,* *Solidago canadensis,* *Panicum sp.,* *Typha latifolia,* *Mikania scandens,* *Andropgon virginicus*	+4 -4 **0**
TOTAL	**33 Species**	**28 Species**	+18 -23 **-5**

5.4.2 Dominant Species in each study.

Table 18: Dominant Species in Each Study. Bold indicates a species that is common to both studies at that site.

Fajardo 2006	Kreisel et al.
Agrostis stolonifera	*Acer rubrum*
Alisma subcordatum	***Alisma subcordatum***
Ambrosia artemisiifolia	*Andropgon virginicus*
Aster novae-angliae	***Aster novae-angliae***
Betula nigra	*Aster vimineus*
Bidens frondosa	***Bidens frondosa***
Carex vulpinoides	*Conoclinium coelestinum*
Diodia virginiana	***Diodia virginiana***
Echinochloa crus-galli	*Echinochloa muricata*
Echinochloa walteri	*Galium tinctorium*
Eleocharis obtusa	***Juncus acuminatus***
Eragrostis pilosa	***Juncus effusus***
Eupatorium capillifolium	***Lespedeza cuneata***
Juncus acuminatus	*Lonicera japonica*
Juncus effusus	***Ludwigia palustris***
Juncus tenuis	*Lycopus virginicus*
Lemna valdiviana	*Microstegium vimineum*
Lespedeza cuneata	*Mikania scandens*
Lindernia dubia	*Panicum sp.*
Lolium perenne	*Panicum clandestinum*
Ludwigia decurrens	*Panicum dichotomiflorum*
Ludwigia palustris	*Panicum scoparium*
Panicum ancepts	*Polygonum hydropiperoides*
Paspalum floridanum	***Scirpus cyperinus***
Polygonum pensylvanicum	*Setaria glauca*
Salix nigra	*Solidago sp.*
Scirpus atrivirens	*Solidago anadensis*
Scirpus cyperinus	***Typha latifolia***
Solidago speciosa	
Trifolium pratensis	
Typha angustifolia	
Typha latifolia	
Vicia sativa	

5.5 Woody Species Frequency

5.5.1 Trees

Table 19: Woody Species Frequency (Trees)

	CCW		*DC*		*MAN*		*MATTA*		*MTS*	
	2006	2008	2006	2008	2006	2008	2006	2008	2006	2008
Acer negundo					1	1				
Acer rubrum	1	1					1	1	1	1
Albizia julibrissin		1								
Alnus serrulata									1	
Betula nigra		1								1
Carya carolinae							1			
Cornus florida										1
Diospyros virginiana										
Fraxinus pennsylvanica					1		1		1	
Ilex opaca										
Ilex verticillata				1						
Liquidambar Styraciflua	1	1						1	1	1
Nyssa sylvatica										
Pinus serotina										
Pinus taeda		1		1					1	1
Platanus occidentalis									1	
Quercus bicolor								1		
Quercus coccinea					1					
Quercus laurifolia		1								
Quercus lyrata									1	
Quercus michauxii							1		1	
Quercus pagodaefolia									1	
Quercus palustris						1			1	1
Quercus Phellos				1		1	1		1	
Salix nigra			1	1			1		1	
Taxodium Distichum	1				1				1	1
Ulmus americana							1		1	
Ulmus rubra										1
TOTAL	3	6	1	4	4	3	7	3	13	8
	9		5		7		10		21	

Table 19 continued

	RCK		*SB*		*SCW*		*SWS*		*TOTAL*	
	2006	**2008**	**2006**	**2008**	**2006**	**2008**	**2006**	**2008**	**2006**	**2008**
Acer negundo									1	1
Acer rubrum	1	1				1	1	1	5	6
Albizia julibrissin								1	0	2
Alnus serrulata									1	0
Betula nigra		1	1		1				2	3
Carya carolinae									1	0
Cornus florida		1							0	2
Diospyros virginiana								1	0	1
Fraxinus pennsylvanica		1	1		1	1			5	2
Ilex opaca								1	0	1
Ilex verticillata									0	1
Liquidambar Styraciflua		1	1			1		1	3	6
Nyssa sylvatica		1							0	1
Pinus serotina							1		1	0
Pinus taeda		1					1	1	2	5
Platanus occidentalis		1	1						2	1
Quercus bicolor									0	1
Quercus coccinea									1	0
Quercus laurifolia		1							0	2
Quercus lyrata			1						2	0
Quercus michauxii									2	0
Quercus pagodaefolia					1		1		3	0
Quercus palustris		1		1		1			1	5
Quercus Phellos									2	2
Salix nigra		1		1	1	1		1	4	5
Taxodium Distichum					1	1	1	1	5	3
Ulmus americana			1						3	0
Ulmus rubra						1			0	2
TOTAL	1	11	6	2	5	7	5	8	46	52
	12		**8**		**12**		**13**		**98**	

5.5.2 Shrub

Table 20: Woody Species Frequency (Shrubs)

	CCW		*DC*		*MAN*		*MATTA*		*MTS*	
	2006	2008	2006	2008	2006	2008	2006	2008	2006	2008
Baccharis halimifolia										
Cephalanthus occidentalis					1	1	1			
Rosa palustris						1				
Rubus allegheniensis		1		1		1				1
Spiraea tomentosa				1						
Symplocos Tinctoria					1					
Viburnum dentatum										1
TOTAL	0	1	0	2	2	3	1	0	1	2
	1		2		5		1		3	

	RCK		***SB***		***SCW***		***SWS***		***TOTAL***	
	2006	**2008**	**2006**	**2008**	**2006**	**2008**	**2006**	**2008**	**2006**	**2008**
Baccharis halimifolia								1	0	1
Cephalanthus occidentalis		1					1	1	3	3
Rosa palustris								1	0	2
Rubus allegheniensis		1						1	0	6
Spiraea tomentosa		1				1			0	3
Symplocos Tinctoria									1	0
Viburnum dentatum									0	1
TOTAL	0	3	0	0	0	1	1	4	4	16
	3		**0**		**1**		**5**		**20**	

5.6 Soil Chroma and Redoximorphic Features

Table 21: Redoximorphic Contrast Evaluation (Schoeneberger et al. 2002)

Class (Code)	**Description**
Faint (F)	Evident only on close inspection. A) Faint features have the same hue as the matrix, but differ from the matrix color by ≤2 in value and ≤1 in chroma.
Distinct (D)	Contrasts moderately with the matrix color. A) Features are distinct when they are the same hue as the matrix, but a) differ between 2< 4 in value, < 4 in chroma; or b) < 4 in value and 1< 4 in chroma. B) Distinct features can also differ by 2.5 hue units when the value is ≤2 in value and ≤1 in chroma.
Prominent (P)	Contrasts strongly with the matrix color. A) Features are the same hue as the matrix color, but value or chroma are ≥4 in value or chroma; or B) Feature differs by 2.5 units from the matrix, value is > 2 or chroma is > 1; or C) Hue differs by at least 5 hue units.

5.6.1 CCW Soil Chroma.

Table 22: CCW Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
CCW1	0-2	2.5Y 4/2.5			some roots, lots of OM
	2-5	2.5Y 4/1.5		7.5YR 5/8 (root channels)/ P; 2.5YR 4/8 (root channels)/P	few fine roots
	5-10	2.5Y 4/1.5		7.5YR 5/8 (root channels)/P; 2.5Y 6/1 (redox feature)/F	few fine roots
	10-15	2.5Y 4/1.5		10YR 6/8 (redox feature)/P 10YR 7/6 (redox feature) /P 10YR 3/2 (redox feature) /P	few fine roots
CCW2	0-2	2.5Y 4/2.5			many fine roots and OM
	2-5	2.5Y 4/2.5		2.5Y 5/6 (root channels)/D; 7.5YR 5/8 (root channels) /P	some roots, some OM
	5-10	2.5Y 4/2.5		5YR 3/4 (root channels) /P; 2.5Y 6/6 (redox feature)/D; 5YR 2.5/2 (root channels) /P	many fine roots
	10-15	2.5Y 4/2	2.5Y 6/1.5	5YR 5/6 (root channels) /P; 7.5YR 5/8 (root channels) /P; 10YR 6/8 (redox feature) /P; 2.5Y 3/2 (redox feature)/F	very few fine roots
CCW3	0-2	2.5Y 5/2			some roots, lots of OM
	2-5	2.5Y 5/2		7.5YR 5/8 (root channels)/P; 2.5Y 5/1 (redox feature)/F; 10YR 5/6 (root channels)/P	few roots, little OM
	5-10	2.5Y 5/1		2.5Y 4/1 (redox feature)/F; 10YR 5/6 (root channels)/P; 2.5Y 7/4 (redox feature)/D; 5YR 5/8 (root channel)/P	few roots, little OM
	10-15	2.5Y 5/2	2.5Y 4/1	2.5Y 6/4 (redox feature)/D; 7.5YR 6/8 (root channels)/P	few roots, little OM
CCW4	0-2	2.5Y 5/2	2.5Y 4/1	2.5Y 7/6 (redox feature)D or P	some roots, some OM
	2-5	2.5Y 5/1.5		2.5Y 6.5/3 (redox feature)D; 10YR 6/8 (redox feature)/P; 2.5Y 4/1 (redox feature)/F	some roots, some OM
	5-10	2.5Y 5/1.5	2.5Y 4/1	2.5Y 6/2 (redox feature)/F; 5YR 5/8 (root channels)/P;	some fine roots, some OM
	10-15	2.5Y 5.5/1		2.5Y 4/1 (redox feature)/F; 7.5YR 5/8 (root channels)/P; 2.5Y 7/4 (redox feature)/D	few fine roots, some OM

Table 22 continued

CCW5	0-2	2.5Y 4/2.5			lots of roots, some OM
	2-5	2.5Y 4/2		2.5Y 6/8 (root channel)/P	some roots, some OM
	5-10	2.5Y 4/2	2.5Y 4/1	10YR 6/8 (root channels)/P	
	10-15	2.5Y 4/1.5	2.5Y 4/1	2.5Y 4/3 (redox feature)/D; 7.5YR 5/8 (root channels)/P	few fine roots
CCW6	0-2	2.5Y 4/1.5			lots of roots and OM
	2-5	2.5Y 4/1.5			
	5-10	2.5Y 4/2		7.5YR 4/6 (redox feature)/P; 7.5YR 2.5/1 (redox feature)/P	very few fine roots
	10-15	2.5Y 4/2.5		7.5YR 4/6 (redox feature)/P	very few roots
CCW7	0-2	2.5Y 3/2			lots of roots and OM
	2-5	2.5Y 3.5/2			lots of fine roots
	5-10	2.5Y 4/2			some fine roots
	10-15	2.5Y 4/2		2.5Y 2.5/1 (redox feature)/F; 5YR 4/6 (redox feature)/P	very few fine roots
CCW8	0-2	2.5Y 4/2			some roots, Lots of OM
	2-5	2.5Y 4.5/2		5YR 5/8 (redox feature)/P	many fine roots, some OM
	5-10	2.5Y 4.5/2		2.5Y 3/1 (redox feature)/F; 2.5Y 5/2 (redox feature)/F; 7.5YR 5/8 (redox feature)/P	few roots, little OM
	10-15	2.5Y 5/1.5		5YR 5/8 (redox feature)/P	very few roots, some OM
CCW9	0-2	2.5Y 4/2	2.5Y 4/3		some roots, lots of OM
	2-5	2.5Y 4/2	2.5Y 4/3; 2.5Y 5/2		few roots, some OM
	5-10	2.5Y 4/2.5		2.5Y 6/2 (redox feature)/F	some roots
	10-15	2.5Y 4/3		5YR 5/8 (root channel)/P	some larger roots
CCW10	0-2	2.5Y 4/3		2.5Y 4/2 (redox feature)/F; 5YR 3/4 (redox feature)/P; 2.5Y 3/1 (redox feature)/D;	many fine roots
	2-5	2.5Y 4/2		2.5Y 4/4 (redox feature)/D; 10YR 3/6 (root channel)/P	some roots
	5-10	2.5Y 4/2		2.5Y 4/3 (redox feature)/F	some roots, some OM
	10-15	2.5Y 4/3		7.5YR 5/8 (root channel)/P	few roots

* See Table 20 for a description

Table 23: CCW Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
CCW1	0-2	2.5Y 4/2.5		10YR 4/0	+2.5
	2-5	2.5Y 4/1.5		7.5YR 6/0	+1.5
	5-10	2.5Y 4/1.5		7.5YR 6/0	+1.5
	10-15	2.5Y 4/1.5		7.5YR 6/0	+1.5
CCW2	0-2	2.5Y 4/2.5		10YR 4/2	+0.5
	2-5	2.5Y 4/2.5		7.5YR 6/0	+2.5
	5-10	2.5Y 4/2.5		7.5YR 6/0	+2.5
	10-15	2.5Y 4/2	2.5Y 6/1.5	7.5YR 6/0	+1.75
CCW3	0-2	2.5Y 5/2		7.5YR 4/0	+2
	2-5	2.5Y 5/2		7.5YR 5/0	+2
	5-10	2.5Y 5/1		7.5YR 5/0	+1
	10-15	2.5Y 5/2	2.5Y 4/1	7.5YR 5/0	+1.5
CCW4	0-2	2.5Y 5/2	2.5Y 4/1	10YR 5/2	**-0.5**
	2-5	2.5Y 5/1.5		10YR 5/2	**-0.25**
	5-10	2.5Y 5/1.5	2.5Y 4/1	10YR 5/2	**-0.75**
	10-15	2.5Y 5.5/1		10YR 5/2 (10-12cm) 7.5YR 5/0 (12-15cm)	**-1**

Table 23 continued

CCW5	0-2	2.5Y 4/2.5		7.5YR 5/0	+2.5
	2-5	2.5Y 4/2		7.5YR 5/0	+2
	5-10	2.5Y 4/2	2.5Y 4/1	7.5YR 5/0	+1.5
	10-15	2.5Y 4/1.5	2.5Y 4/1	7.5YR 5/0	+1.25
CCW6	0-2	2.5Y 4/1.5		10YR 5/3	**-1.5**
	2-5	2.5Y 4/1.5		10YR 5/3	**-1.5**
	5-10	2.5Y 4/2		10YR 5/3	**-1**
	10-15	2.5Y 4/2.5		10YR 5/4	**-1.5**
CCW7	0-2	2.5Y 3/2		10YR 4/2	0
	2-5	2.5Y 3.5/2		10YR 4/2	0
	5-10	2.5Y 4/2		10YR 4/2 (5-8cm) 10YR 5/1 (8-10cm)	+0.4
	10-15	2.5Y 4/2		10YR 5/1	+1
CCW8	0-2	2.5Y 4/2		10YR 4/2	0
	2-5	2.5Y 4.5/2		10YR 4/2	0
	5-10	2.5Y 4.5/2		10YR 4/2 (5-8cm) 10YR 7/1 (8-10cm)	+0.4
	10-15	2.5Y 5/1.5		10YR 7/1	+0.5
CCW9	0-2	2.5Y 4/2	2.5Y 4/3	10YR 5/2	+0.5
	2-5	2.5Y 4/2		10YR 5/2	0
	5-10	2.5Y 4/2.5		10YR 5/2	+0.5
	10-15	2.5Y 4/3		10YR 5/1	+2
CCW10	0-2	2.5Y 4/3		10YR 4/2	+1
	2-5	2.5Y 4/2		10YR 4/2	0
	5-10	2.5Y 4/2		10YR 4/2 (5-8cm) 10YR 5.5/1 (8-10cm)	+0.4
	10-15	2.5Y 4/3		10YR 5.5/1	+2

5.6.2 DC Soil Chroma.

Table 24: DC Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
DC1	0-2	10YR 4/4			lots of OM
	2-5	10YR 4/3.5		7.5YR 4/6 (redox feature)/P	some roots, some OM
	5-10	10YR 4/3.5		5YR 4/6 (root channels)/P	some roots, some OM
	10-15	10YR 4/4			some fine roots, some OM
DC2	0-2	2.5Y 4.5/2.5			lots of OM
	2-5	10YR 3.5/3			lots of very fine roots
	5-10	10YR 3/ 5			some roots
	10-15	10YR 3.5/3.5		10YR 7/6 (redox feature)/D	some larger roots
DC 3	0-2	2.5Y 3/3			much OM
	2-5	10 YR 4/3		2.5YR 4/6 (root channels)/P	many roots
	5-10	10YR 4/2.5		2.5YR 3/4 (redox feature)/P; 2.5YR 2.5/1 (redox feature)/P	some roots, some OM
	10-15	10 YR 4/3		5YR 4/6 (root channels)/P	some roots some OM
DC 4	0-2	10YR 3.5/4			lots of roots, lots of OM
	2-5	10YR 4/3.5		5YR 5/8 (redox feature)/P	lots of fine roots, some OM
	5-10	10YR 3.5/4		10YR 6/3 (redox feature)/D; 5YR 5/8 (root channels)/P	some fine roots
	10-15	10YR 3/3.5		10YR 5/4 (redox feature)/F; 10YR 2/1 (redox feature)/F; 5YR 3/4 (redox feature)/P; 7.5YR 5/8 (redox feature)/P	some roots
DC 6	0-2	10YR 4/4	10YR 3/2		lots of roots and some OM
	2-5	10YR 4/3.5			some roots
	5-10	10YR 4/3		5YR 4/6 (root channels)/P	some roots
	10-15	10YR 4/3		2.5Y 5/4 (redox feature)/P	some roots
DC 7	0-2	2.5Y 4/4			lots of fine roots, some OM
	2-5	10YR 4/3		2.5YR 4/8 (root channels)/P	some fine roots
	5-10	2.5Y 4/3	10YR 4/4	2.5Y 6/4 (redox feature)/F or P	some OM
	10-15	10YR 4/3.5		10YR 6/3 (redox feature)/F; 10YR 5/8 (redox feature)/D	

Table 24 continued

DC 8	0-2	10YR 4/3			lots of fine roots
	2-5	10YR 4/3			some fine roots
	5-10	10YR 4/2.5	10YR 4/4		some fine roots
	10-15	10YR 3/5	10YR 4/3	10YR 6/5 (redox feature)/D	some roots
DC 9	0-2	2.5Y 4/4		7.5YR 4/6 (root channels)/P	
	2-5	2.5Y 4/4		2.5Y 6/3 (redox feature)/F; 2.5Y 4/1 (redox feature)/D; 5YR 5/8 (root channels) /P	some roots
	5-10	10YR 4/4			
	10-15	2.5Y 4/4		5YR 4/6 (root channels) /P	some very fine roots
DC 10	0-2	10YR 4/3	2.5Y 4/2	5YR 5/8 (root channel) /P	many fine roots and OM
	2-5	10YR 4/4			some roots
	5-10	10YR 3/5		7.5YR 4/5 (redox feature) /P; 2.5Y 3/1 (redox feature) /P	some fine roots
	10-15	10YR 4/3.5		5YR 4.5/7 (root channel) /P; 10YR 3/2 (redox feature)/D	some roots

* See Table 20 for a description

Table 25: DC Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
DC1	0-2	10YR 4/4		10YR 4/3	+1
	2-5	10YR 4/3.5		10YR 4/3	+0.5
	5-10	10YR 4/3.5		10YR 4/3 (5-8cm) 10YR 6/4 (8-10cm)	+0.5
	10-15	10YR 4/4		10YR 6/4	0
DC2	0-2	2.5Y 4.5/2.5		7.5YR 4/6	**-3.5**
	2-5	10YR 3.5/3		7.5YR 4/6	**-3**
	5-10	10YR 3/ 5		7.5YR 4/6	**-1**
	10-15	10YR 3.5/3.5		7.5YR 4/6	**-2.5**
DC 3	0-2	2.5Y 3/3		10YR 5/4	**-1**
	2-5	10 YR 4/3		10YR 5/4	**-1**
	5-10	10YR 4/2.5		10YR 5/4	**-1.5**
	10-15	10 YR 4/3		10YR 7/2	**+1**
DC 4	0-2	10YR 3.5/4		10YR 4/4	**0**
	2-5	10YR 4/3.5		10YR 4/4	**-0.5**
	5-10	10YR 3.5/4		10YR 4/4	**0**
	10-15	10YR 3/3.5		10YR 6/4	**-0.5**
DC 6	0-2	10YR 4/4	10YR 3/2	7.5YR 4/4	**0**
	2-5	10YR 4/3.5		7.5YR 4/4	**-0.5**
	5-10	10YR 4/3		7.5YR 4/4	**-1**
	10-15	10YR 4/3		7.5YR 4/4	**-1**
DC 7	0-2	2.5Y 4/4		7.5YR 5/4	0
	2-5	10YR 4/3		7.5YR 5/4 (2-3cm) 10YR 7/1 (3-5cm)	+1
	5-10	2.5Y 4/3	10YR 4/4	10YR 7/1	+2.5
	10-15	10YR 4/3.5		10YR 7/1	+2.5
DC 8	0-2	10YR 4/3		7.5YR 4/4	**-1**
	2-5	10YR 4/3		7.5YR 4/4	**-1**
	5-10	10YR 4/2.5	10YR 4/4	7.5YR 4/4	**-0.75**
	10-15	10YR 3/5	10YR 4/3	7.5YR 4/4	**0**
DC 9	0-2	2.5Y 4/4		7.5YR 5/4	0
	2-5	2.5Y 4/4		7.5YR 5/4	0
	5-10	10YR 4/4		10YR 5/1	+3
	10-15	2.5Y 4/4		10YR 5/1	+3
DC 10	0-2	10YR 4/3	2.5Y 4/2	7.5YR 4/6	**-3.5**
	2-5	10YR 4/4		7.5YR 4/6	**-2**
	5-10	10YR 3/5		7.5YR 4/6	**-1**
	10-15	10YR 4/3.5		2.5Y 4/2	**+1.5**

5.6.3 MAN Soil Chroma.

Table 26: MAN Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
MAN1	0-2	10YR 4/4		7.5YR 2.5/3 (redox feature)/P	many roots and OM
	2-5	10YR 4/3.5		10YR 3/1 (redox feature)/D; 10YR 5/6 (redox feature)/D	some roots, some OM
	5-10	10YR 4/3		10YR 5/5 (redox feature)/F; 2.5YR 4/6 (redox feature) /P	some roots, some OM
	10-15	10YR 3.5/3.5		5YR 4/4 (redox feature) /P; 10YR 5/6 (redox feature)/D; 2.5YR 3/6 (redox feature) /P	few roots, little OM
MAN2	0-2	10YR 4/4			many fine roots and OM
	2-5	10YR 4/4	7.5YR 3/4	7.5YR 3/2 (redox feature)/ D or P	some roots
	5-10	10YR 4/4	7.5YR 4/4	10YR 5/6 (redox feature)/ D or P	some roots
	10-15	7.5YR 4/4		10YR 5/6 (redox feature)/P	some roots
MAN3	0-2	7.5YR 3/4			many fine roots, some OM
	2-5	7.5YR 4/4		2.5YR 2.5/1 (redox feature)/P; 5YR 4/6 (redox feature) /P; 7.5YR 4/6 (redox feature)/D	some roots, some OM
	5-10	7.5YR 3/4		5YR 4/4 (redox feature) /P	some roots
	10-15	7.5YR 3/4		10YR 5/6 (redox feature) /P; 10YR 6/1.5 (redox feature) /P	few roots
MAN4	0-2	7.5YR 4/4		7.5YR 2.5/1 (redox feature)/D	many roots, some OM
	2-5	7.5YR 4/4			some roots
	5-10	7.5YR 3.5/4	10YR 4/4		few fine roots
	10-15	7.5YR 3/4		2.5YR 4/6 (redox feature) /P; 2.5Y 6/1 (redox feature) /P	some larger roots
MAN6	0-2	10YR 3/5			many fine roots, some OM
	2-5	7.5YR 3.5/4	7.5YR 3/4		many fine roots
	5-10	7.5YR 3.5/4		7.5YR 5/6 (redox feature)/D; 7.5YR 4/6 (redox feature)/D	few roots
	10-15	7.5YR 3.5/4		7.5YR 3/4 (redox feature)/F	few fine roots, little OM

Table 26 continued

MAN7	0-2	7.5YR 3/4	7.5YR 4/4		some roots, lots of OM
	2-5	7.5YR 4/4			few roots
	5-10	7.5YR 4/4		7.5YR 3/3 (redox feature)/F	very few fine roots
	10-15	7.5YR 3/4			very few fine roots
MAN8	0-2	7.5YR 4/4			many fine roots
	2-5	7.5YR 4/4		10YR 5/3 (redox feature)/P	some fine roots
	5-10	7.5YR 4/4		5YR 5/6 (redox feature) /P	some fine and larger roots, little OM
	10-15	5YR 4/4		5YR 5/6 (redox feature)/D; 7.5YR 6/6 (redox feature) /P	few fine roots, little OM
MAN9	0-2	7.5YR 3.5/4			few roots, little OM
	2-5	7.5YR 4/4		7.5YR 2.5/1 (redox feature)/D; 7.5YR 4/6 (redox feature)/D	few roots, little OM
	5-10	7.5YR 3.5/4		5YR 5/6 (redox feature)/P; 5YR 5/8 (redox feature)/P; 7.5YR 4/4 (redox feature)/F; 2.5YR 2.5/1 (redox feature)/P	few roots, some OM
	10-15	7.5YR 3.5/4		5YR 5/8 (redox feature)/P	few roots, little OM
MAN10	0-2	7.5YR 4/4			many fine roots, some OM
	2-5	7.5YR 4/4			many fine roots, lots of OM
	5-10	7.5YR 4/4		7.5YR 3/4 (redox feature)/F; 2.5YR 4/6 (redox feature)/P	few roots
	10-15	7.5YR 4/3		2.5YR 3/6 (redox feature)/P; 7.5YR 5/6 (redox feature)/D	few fine roots

* See Table 20 for a description

Table 27: MAN Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
MAN1	0-2	10YR 4/4		7.5YR 5/4	**0**
	2-5	10YR 4/3.5		7.5YR 5/4	**-0.5**
	5-10	10YR 4/3		7.5YR 5/4	**-1**
	10-15	10YR 3.5/3.5		7.5YR 5/4	**-0.5**
MAN2	0-2	10YR 4/4		7.5YR 5/4	0
	2-5	10YR 4/4	7.5YR 3/4	7.5YR 5/4	0
	5-10	10YR 4/4	7.5YR 4/4	7.5YR 5/4	0
	10-15	7.5YR 4/4		7.5YR 5/4	0
MAN3	0-2	7.5YR 3/4		7.5YR 5/6	**-2**
	2-5	7.5YR 4/4		7.5YR 5/6	**-2**
	5-10	7.5YR 3/4		7.5YR 5/6	**-2**
	10-15	7.5YR 3/4		7.5YR 5/6 (10-13cm) 5YR 4/6 (13-15cm)	**-2**
MAN4	0-2	7.5YR 4/4		7.5YR 5/4	**0**
	2-5	7.5YR 4/4		7.5YR 5/4	**0**
	5-10	7.5YR 3.5/4	10YR 4/4	7.5YR 5/4	**0**
	10-15	7.5YR 3/4		7.5YR 5/4 (10-13cm) 5YR 5/8 (13-15cm)	**-1.6**
MAN6	0-2	10YR 3/5		7.5YR 4/4	+1
	2-5	7.5YR 3.5/4	7.5YR 3/4	7.5YR 4/4	0
	5-10	7.5YR 3.5/4		7.5YR 4/4	0
	10-15	7.5YR 3.5/4		7.5YR 4/4	0
MAN7	0-2	7.5YR 3/4	7.5YR 4/4	5YR 5/8	**-4**
	2-5	7.5YR 4/4		5YR 5/8	**-4**
	5-10	7.5YR 4/4		5YR 5/8	**-4**
	10-15	7.5YR 3/4		5YR 5/8	**-4**

Table 27 continued

MAN8	0-2	7.5YR 4/4	5YR 5/6	**-2**
	2-5	7.5YR 4/4	5YR 5/6	**-2**
	5-10	7.5YR 4/4	5YR 5/6	**-2**
	10-15	5YR 4/4	5YR 5/8	**-4**
MAN9	0-2	7.5YR 3.5/4	5YR 5/8	**-4**
	2-5	7.5YR 4/4	5YR 5/8	**-4**
	5-10	7.5YR 3.5/4	5YR 5/8	**-4**
	10-15	7.5YR 3.5/4	5YR 4/6	**-2**
MAN10	0-2	7.5YR 4/4	5YR 5/6	**-2**
	2-5	7.5YR 4/4	5YR 5/6	**-2**
	5-10	7.5YR 4/4	5YR 5/6	**-2**
	10-15	7.5YR 4/3	5YR 5/6 (10-13cm) 10YR 6/6 (13-15cm)	**-3**

5.6.4 MATTA Soil Chroma.

Table 28: MATTA Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
MATTA1	0-2	2.5Y 3/2			lots of roots and OM
	2-5	2.5Y 4/2			some fine roots
	5-10	2.5Y 4/2.5		10YR 5/6 (redox feature)/P	some fine roots
	10-15	2.5Y 3/2		10YR 5/8 (redox feature)/P	some fine roots and OM
MATTA2	0-2	2.5Y 3/2			lots of fine roots and OM
	2-5	2.5Y 3/2	2.5Y 4/2	2.5YR 5/8 (root channels)/P; 2.5Y 6/3 (redox feature)/D or F	
	5-10	2.5Y 3.5/2		10YR 6/6 (redox feature)/P	
	10-15	2.5Y 3/2		5YR 4/6 (redox feature)/P; 2.5Y 6/3 (redox feature)/D	some fine roots
MATTA3	0-2	2.5Y 3/2.5			
	2-5	2.5Y 3.5/2.5			
	5-10	2.5Y 3/2.5		2.5Y 2.5/1 (redox feature)/D; 2.5Y 6/3 (redox feature)/D	some roots, some OM
	10-15	2.5Y 3.5/2		2.5Y 7/6 (redox feature)/D; 10YR 2/2 (redox feature)/P	
MATTA4	0-2	5Y 2.5/2			many fine roots
	2-5	2.5Y 3/2			some roots, some OM
	5-10	2.5Y 3/2		10YR 6/6 (redox feature)/P; 2.5Y 2.5/1 (redox feature)/F	some fine roots
	10-15	2.5Y 3/2		2.5Y 2.5/1 (redox feature)/F; 2.5Y 4/4 (redox feature)/D	some fine roots
MATTA5	0-2	2.5Y 3/2.5			lots of fine roots and OM
	2-5	2.5Y 4/2			lots of fine roots and OM
	5-10	2.5Y 3.5/2		10YR 6/8 (redox feature)/P 10YR 5/8 (redox feature)/P 2.5YR 2.5/4 (redox feature)/D	
	10-15	2.5Y 4/2.5		2.5Y 6/4 (redox feature)/D	some roots and OM
MATTA6	0-2	2.5Y 3/2	2.5Y 4/2.5		lots of fine roots and OM
	2-5	2.5Y 3.5/2			some fine roots
	5-10	2.5Y 3.5/2		10YR 6/7 (redox feature)/P	some fine roots
	10-15	2.5Y 4/2.5			some fine roots

Table 28 continued

MATTA7	0-2	2.5Y 3/2	2.5Y 4/2.5		lots of fine roots and OM
	2-5	2.5Y 3.5/2			some fine roots
	5-10	2.5Y 3.5/2		10YR 6/7 (redox feature)/P	
	10-15	2.5Y 4/2.5			some fine roots
MATTA8	0-2	2.5Y 3/2	10YR 2/1		lots of roots and OM
	2-5	2.5Y 4/2.5		2.5Y 6/4 (redox feature)/D; 5YR 4/6 (redox feature)/P	many fine roots, some OM
	5-10	2.5Y 3.5/2		10YR 5/8 (redox feature)/P; 10YR 6/8 (redox feature)/P	some larger roots
	10-15	2.5Y 3/2		10YR 5.5/6 (redox feature)/P	some roots, some OM
MATTA9	0-2	2.5Y 3/2		2.5Y 6/6 (redox feature)/P	lots of roots and OM
	2-5	2.5Y 3/2		2.5Y 4/3 (redox feature)/F	some roots, some OM
	5-10	2.5Y 3.5/2		2.5Y 5/4 (redox feature)/D; 10YR 3/6 (redox feature)/P	some larger roots
	10-15	2.5Y 3.5/2			some fine roots
MATTA10	0-2	2.5Y 3/2	2.5Y 4/2	2.5Y 6/2 (redox feature)/ D or F	lots of roots, some OM
	2-5	2.5Y 3/2		2.5Y 2.5/1 (redox feature)/F; 10YR 3/6 (redox feature)/P; 10YR 7/6 (redox feature)/P	
	5-10	2.5Y 3/2		2.5Y 6/6 (redox feature)/P; 10YR 3/6 (redox feature)/P	some roots, some OM
	10-15	2.5Y 4/2.5		2.5Y 2.5/1 (redox feature)/D; 2.5Y 5/4 (redox feature)/D	some roots, some OM

* See Table 20 for a description

Table 29: MATTA Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
MATTA1	0-2	2.5Y 3/2		10YR 4/3 and 10YR 5/8	**-3.5**
	2-5	2.5Y 4/2		10YR 4/3 and 10YR 5/8	**-3.5**
	5-10	2.5Y 4/2.5		10YR 4/3 and 10YR 5/8	**-3**
	10-15	2.5Y 3/2		10YR 4/3 and 10YR 5/8	**-3.5**
MATTA2	0-2	2.5Y 3/2		10YR 5/3 and 7.5YR 5/0	+0.5
	2-5	2.5Y 3/2	2.5Y 4/2	10YR 5/3 and 7.5YR 5/0	+0.5
	5-10	2.5Y 3.5/2		10YR 5/3 and 7.5YR 5/0	+0.5
	10-15	2.5Y 3/2		10YR 5/3 and 7.5YR 5/0	+0.5
MATTA3	0-2	2.5Y 3/2.5		10YR 4/3	**-0.5**
	2-5	2.5Y 3.5/2.5		10YR 4/3	**-0.5**
	5-10	2.5Y 3/2.5		10YR 4/3	**-0.5**
	10-15	2.5Y 3.5/2		10YR 4/3	**-1**
MATTA4	0-2	5Y 2.5/2		10YR 4/3 and 7.5YR 6/8	**-3**
	2-5	2.5Y 3/2		10YR 4/3 and 7.5YR 6/8	**-3**
	5-10	2.5Y 3/2		10YR 4/3 and 7.5YR 6/8	**-3**
	10-15	2.5Y 3/2		10YR 4/3 and 7.5YR 6/8	**-3.5**
MATTA5	0-2	2.5Y 3/2.5		10YR 4/3	**-0.5**
	2-5	2.5Y 4/2		10YR 4/3	**-1**
	5-10	2.5Y 3.5/2		10YR 4/3	**-1**
	10-15	2.5Y 4/2.5		10YR 4/3	**-0.5**
MATTA6	0-2	2.5Y 3/2	2.5Y 4/2.5	10YR 4/3 and 7.5YR 6/8	**-3.25**
	2-5	2.5Y 3.5/2		10YR 4/3 and 7.5YR 6/8	**-3.5**
	5-10	2.5Y 3.5/2		10YR 4/3 and 7.5YR 6/8	**-3.5**
	10-15	2.5Y 4/2.5		10YR 4/3 and 7.5YR 6/8	**-3**

Table 29 continued

MATTA7	0-2	2.5Y 3/2	10YR 4/3	**-1**
	2-5	2.5Y 3.5/2	10YR 4/3	**-1**
	5-10	2.5Y 3.5/2	10YR 4/3	**-1**
	10-15	2.5Y 4/2.5	10YR 4/3 (10-14cm) 2.5Y 4/0 (14-15cm)	**+0.5**
MATTA8	0-2	2.5Y 3/2	10YR 4/3	**-1**
	2-5	2.5Y 4/2.5	10YR 4/3	**-0.5**
	5-10	2.5Y 3.5/2	10YR 4/3	**-1**
	10-15	2.5Y 3/2	10YR 4/3	**-1**
MATTA9	0-2	2.5Y 3/2	10YR 4/3	**-1**
	2-5	2.5Y 3/2	10YR 4/3	**-1**
	5-10	2.5Y 3.5/2	10YR 4/3	**-1**
	10-15	2.5Y 3.5/2	10YR 4/3	**-1**
MATTA10	0-2	2.5Y 3/2	10YR 4/3	**-1**
	2-5	2.5Y 3/2	10YR 4/3	**-1**
	5-10	2.5Y 3/2	10YR 4/3	**-1**
	10-15	2.5Y 4/2.5	10YR 4/3	**-0.5**

5.6.5 MTS Soil Chroma.

Table 30: MTS Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
MTS1	0-2	2.5Y 3/2.5			some roots, some OM
	2-5	2.5Y 3/3		2.5Y 5/3 (redox feature)/F 7.5YR 5/8 (root channel)/P	some roots
	5-10	2.5Y 3/2		2.5Y 5/4 (redox feature)/D; 2.5Y 4/4 (redox feature)/D; 7.5YR 5/8 (root channels)/P; 2.5Y 3/1 (redox feature)/F	some roots
	10-15	2.5Y 3/3		2.5Y 5/4 (redox feature)/F; 5YR 5/8 (redox feature)/P	few roots
MTS2	0-2	2.5Y 3/2.5		2.5Y 5/2 (redox feature)/F	some roots and OM
	2-5	2.5Y 3/3		5YR 4/6 (redox feature) /P	some fine and some larger (1.5mm roots)
	5-10	2.5Y 3/3		10YR 7/3 (redox feature)/P; 10YR 5/8 (redox feature)/P	fine roots
	10-15	2.5Y 5/3	2.5Y 4/2	5YR 4/6 (redox feature)/P	very few roots
MTS3	0-2	2.5Y 4/2			some roots and OM
	2-5	2.5Y 4/2		5YR 5/6 (redox feature)/P; 5Y 2.5/1 (large redox features)/P	lots of fine roots
	5-10	2.5Y 4/2.5		5YR 5/8 (redox feature)/P; 5YR 4/6 (redox feature)/P	some fine roots and OM
	10-15	2.5Y 4/2.5		5YR 5/8 (redox feature)/P	some roots, some OM
MTS4	0-2	2.5Y 3/3			lots of OM
	2-5	2.5Y 3/3			some roots
	5-10	2.5Y 3/3			very few roots
	10-15	2.5Y 4/3			very few roots
MTS5	0-2	2.5Y 4/3			many roots, some OM
	2-5	2.5Y 4/3.5		2.5Y 4/2 (redox feature)/D; 5YR 5/8 (redox feature, root channels)/P	many fine roots
	5-10	2.5 Y 4/3		10Y 7/6 (redox feature)/P; 10YR 5/8 (root channels)/P	some roots and OM
	10-15	2.5Y 4/4		2.5Y 6/4 (redox feature)/F; 5YR 5/8 (root channels)/P	

Table 30 continued

MTS6	0-2	2.5 Y 4/3			some roots and some OM
	2-5	2.5Y 4/2		10YR 5/8 (root channels)/P	some roots and some OM
	5-10	2.5Y 4/2	2.5Y 3/2	10YR 7/8 (redox feature)/P; 7.5YR 4/6 (redox feature)/P	some fine roots and OM
	10-15	2.5Y 3/2	2.5 Y 4/3	2.5YR 5/8 (root channels)/P	some fine roots
MTS7	0-2	2.5Y 3.5/2			some roots
	2-5	2.5Y 3.5/2		7.5YR 5/8 (redox feature)/P	some roots
	5-10	2.5Y 3/2		2.5Y 5/3 (redox feature)/F 7.5YR 5/8 (redox feature)/P	some roots
	10-15	2.5Y 4/2		2.5Y 6/6 (redox feature)/P	some roots
MTS8	0-2	2.5Y 4/2.5			lots of roots and OM
	2-5	2.5 Y 4/3		7.5YR 6/8 (redox feature)/P	very fine roots
	5-10	2.5 Y 4/3	2.5Y 4/2	2.5Y 6/6 (redox feature)/ D or P; 7.5YR 4/6 (root channels)/P	very fine roots
	10-15	2.5Y 5/4	2.5Y 4/2	5 YR 5/8 (root channels, redox feature)/P	some roots
MTS9	0-2	10YR 3/2		5 YR 5/8 (root channel)/P	lots of very fine roots
	2-5	2.5Y 3.5/2		7.5 YR 5/8 root channels)/P	some very fine roots
	5-10	2.5Y 4/2		10YR 7/6 (redox feature)/P; 5YR 5/8 (redox feature)/P	some very fine roots
	10-15	2.5Y 4/2		10YR 6/3 (redox feature)/P; 7.5YR 5/8 (redox feature)/P	very few roots
MTS10	0-2	2.5Y 3/1.5			some roots, lots of OM
	2-5	2.5Y 3/1.5			few roots, some OM
	5-10	10YR 3/2			some very fine roots
	10-15	2.5Y 3.5/2		5YR 4/6 (root channels)/P	few roots, some OM

* See Table 20 for a description

Table 31: MTS Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
MTS1	0-2	2.5Y 3/2.5		5Y 4/2	+0.5
	2-5	2.5Y 3/3		5Y 4/2	+1
	5-10	2.5Y 3/2		5Y 4/2	0
	10-15	2.5Y 3/3		5Y 4/2	+1
MTS2	0-2	2.5Y 3/2.5		10YR 4/2	+0.5
	2-5	2.5Y 3/3		10YR 4/2	+1
	5-10	2.5Y 3/3		10YR 4/2	+1
	10-15	2.5Y 5/3	2.5Y 4/2	10YR 4/2	+0.5
MTS3	0-2	2.5Y 4/2		2.5Y 4/2	0
	2-5	2.5Y 4/2		2.5Y 4/2	0
	5-10	2.5Y 4/2.5		2.5Y 4/2	+0.5
	10-15	2.5Y 4/2.5		2.5Y 4/2	+0.5
MTS4	0-2	2.5Y 3/3		2.5Y 4/3	0
	2-5	2.5Y 3/3		2.5Y 4/3	0
	5-10	2.5Y 3/3		2.5Y 4/3	0
	10-15	2.5Y 4/3		2.5Y 4/3	0
MTS5	0-2	2.5Y 4/3		2.5Y 5/3	0
	2-5	2.5Y 4/3.5		2.5Y 5/3	+0.5
	5-10	2.5 Y 4/3		2.5Y 5/3	0
	10-15	2.5Y 4/4		2.5Y 5/3	+1
MTS6	0-2	2.5 Y 4/3		2.5Y 5/2	+1
	2-5	2.5Y 4/2		2.5Y 5/2	0
	5-10	2.5Y 4/2	2.5Y 3/2	2.5Y 5/2	0
	10-15	2.5Y 3/2	2.5 Y 4/3	2.5Y 5/2	+0.5

Table 31 continued

MTS7	0-2	2.5Y 3.5/2		2.5Y 4/3	**-1**
	2-5	2.5Y 3.5/2		2.5Y 4/3	**-1**
	5-10	2.5Y 3/2		2.5Y 4/3	**-1**
	10-15	2.5Y 4/2		2.5Y 4/3	**-1**
MTS8	0-2	2.5Y 4/2.5		2.5Y 4/3	**-0.5**
	2-5	2.5 Y 4/3		2.5Y 4/3	**0**
	5-10	2.5 Y 4/3	2.5Y 4/2	2.5Y 4/3	**-0.5**
	10-15	2.5Y 5/4	2.5Y 4/2	2.5Y 4/3	**0**
MTS9	0-2	10YR 3/2		10YR 4/2	**0**
	2-5	2.5Y 3.5/2		10YR 4/2	**0**
	5-10	2.5Y 4/2		10YR 4/2	**0**
	10-15	2.5Y 4/2		10YR 4/2 (10-13cm) 10YR 5/6 (13-15cm)	**-1.6**
MTS10	0-2	2.5Y 3/1.5		10YR 3/2	**-0.5**
	2-5	2.5Y 3/1.5		10YR 3/2	**-0.5**
	5-10	10YR 3/2		10YR 3/2 (5-7cm) 2.5Y 6/2 (7-10cm)	**0**
	10-15	2.5Y 3.5/2		2.5Y 6/2	**0**

5.6.6 RCK Soil Chroma.

Table 32: RCK Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
RCK1	0-2	10YR 4/3.5			lots of roots and OM
	2-5	10YR 4/3		7.5YR 5/8 (redox feature)/P	some roots and OM
	5-10	10YR 4/4		2.5Y 4/2 (redox feature)/P	some roots
	10-15	10YR 4/4		7.5YR 5/8 (redox feature)/P	some roots
RCK2	0-2	10YR 4/3			roots and lots of OM
	2-5	10YR 4/4			some roots
	5-10	10YR 4/3.5		5YR 5/6 (redox feature)/P	some roots
	10-15	10YR 4/4			some roots
RCK4	0-2	10YR 4/3		10YR 3/2 (redox feature)/F; 5YR 5/8 (root channels)/P	some fine roots
	2-5	10YR 4/3		5YR 5/8 (redox feature)/P	some roots
	5-10	10YR 4/2.5		5YR 5/8 (redox feature)/P; 10YR 6/6 (redox feature)/D	some roots
	10-15	10YR 4/3		5YR 5/8 (redox feature)/P	
RCK5	0-2	2.5Y 4/4		2.5Y 5/2 (redox feature)/D; 5YR 5/8 (redox feature)/P	some roots and OM
	2-5	2.5Y 4/4		10YR 5/8 (root channels)/P; 5YR 5/8 (redox feature)/P	some roots and OM
	5-10	2.5Y 4/4		5YR 4/6 (redox feature)/P	some very fine roots
	10-15	2.5Y 4/4		5YR 5/8 (redox feature)/P	some roots
RCK6	0-2	2.5Y 4/4			lots of fine roots and OM
	2-5	2.5Y 4/4		5YR 5/8 (redox feature)/P	some roots, some OM
	5-10	2.5Y 4/4		5YR 5/8 (redox feature)/P	some roots some OM
	10-15	2.5Y 4/4		5YR 5/6 (redox feature)/P	some roots some OM
RCK7	0-2	2.5Y 4/4			lots of roots and OM
	2-5	2.5Y 4/4		5YR 5/8 (redox feature)/P	many fine roots
	5-10	2.5Y 4/4		2.5YR 5/8 (redox feature)/P	some fine roots
	10-15	2.5Y 4/4		5YR 4.5/7 (redox feature)/P	some fine roots
RCK8	0-2	10YR 4/3	2.5Y 3/3		many fine roots
	2-5	10YR 4/3		5YR 5/8 (redox feature)/P	some larger roots
	5-10	10YR 4/3		5YR 5/8 (redox feature)/P; 10YR 5/8 (redox feature)/P; 5YR 2.5/1 (redox feature)/P	some fine roots
	10-15	10YR 4/3		2.5YR 4/8 (redox feature)/P; 2.5YR 5/8 (redox feature)/P	few fine roots

Table 32 continued

RCK9	0-2	10YR 2/1	2.5Y 4/2.5	7.5YR 5/8 (redox feature)/P	many roots and OM
	2-5	2.5Y 4/4		2.5Y 5/2.5 (redox feature)/D; 10YR 2/1 (redox feature)/P; 5YR 5/8 (redox feature)/P	some roots
	5-10	2.5Y 4/4		10YR 6/4 (redox feature)/P; 5YR 5/8 (redox feature)/P; 10YR 2/1 (redox feature)/P	some larger roots and OM
	10-15	2.5Y 4/4		10YR 2/1 (redox feature)/P; 5YR 5/8 (redox feature)/P	some roots
RCK10	0-2	7.5YR 2.5/1	2.5Y 4/4	2.5Y 4/3 (redox feature)/P or F; 2.5Y 5/4 (redox feature)/P or F	lots of fine roots and OM
	2-5	2.5Y 4/4		5YR 5/8 (redox feature)/P	many roots and some larger ones
	5-10	2.5Y 4/4		5YR 5/8 (redox feature)/P; 2.5Y 4/3 (redox feature)/F	many fine roots
	10-15	2.5Y 4/4		2.5YR 5/8 (redox feature)/P; 2.5Y 6/3 (redox feature)/F	some fine roots and OM
RCK11	0-2	2.5Y 4/4			lots of roots and OM
	2-5	2.5Y 4/4		7.5YR 5/8 (redox feature)/P; 2.5YR 5/8 (redox feature)/P	some roots
	5-10	2.5Y 4/4		5YR 5/8 (redox feature and root channels)/P	many roots
	10-15	2.5Y 4/4		5YR 5/8 (redox feature)/P	few fine roots
RCK12	0-2	2.5Y 3/3			many fine roots and OM
	2-5	2.5Y 3/3			some roots and OM
	5-10	2.5Y 3/3		7.5YR 5/6 (root channels)/P; 2.5YR 2.5/1 (redox feature)/D	some roots
	10-15	2.5Y 4/4		5YR 2.5/2 (root channels)/P; 5YR 5/8 (redox feature)/P; 10YR5/6 (redox feature)/P	
RCK13	0-2	2.5Y 4/4	2.5Y 3/3		many fine roots and OM
	2-5	2.5Y 4/4		5YR 5/8 (redox feature)/P	some fine roots
	5-10	2.5Y 4/4		10YR 2/2 (redox feature)/P	some roots
	10-15	2.5Y 4/3.5		5YR 5/8 (redox feature)/P	few roots
RCK14	0-2	2.5Y 4/4	2.5Y 3/3	7.5YR 5/8 (redox feature)/P	lots of roots and OM
	2-5	2.5Y 4/4		7.5YR 5/8 (redox feature)/P	some roots
	5-10	2.5Y 4/4		5YR 4/6 (redox feature)/P	a couple larger roots
	10-15	2.5Y 4/4		5YR 5/8 (redox feature)/P	

* See Table 20 for a description

Table 33: RCK Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
RCK1	0-2	10YR 4/3.5		5Y 4/2	+1.5
	2-5	10YR 4/3		5Y 4/2	+1
	5-10	10YR 4/4		5Y 4/2	+2
	10-15	10YR 4/4		5Y 4/2	+2
RCK2	0-2	10YR 4/3		10YR 4/2	+1
	2-5	10YR 4/4		10YR 4/2	+2
	5-10	10YR 4/3.5		10YR 4/2 (5-9cm) 10YR 4/6 (9-10cm)	+2
	10-15	10YR 4/4		10YR 4/5	-1
RCK4	0-2	10YR 4/3		5Y 4/1 and 2.5Y 4/2	+1.5
	2-5	10YR 4/3		5Y 4/1 and 2.5Y 4/2	+1.5
	5-10	10YR 4/2.5		5Y 4/1 and 2.5Y 4/2	+1
	10-15	10YR 4/3		5Y 4/1 and 2.5Y 4/2	+1.5
RCK5	0-2	2.5Y 4/4		2.5Y 4/2	+2
	2-5	2.5Y 4/4		2.5Y 4/2	+2
	5-10	2.5Y 4/4		2.5Y 4/2	+2
	10-15	2.5Y 4/4		2.5Y 4/2	+2
RCK6	0-2	2.5Y 4/4		2.5Y 5/3	+1
	2-5	2.5Y 4/4		2.5Y 5/3	+1
	5-10	2.5Y 4/4		2.5Y 5/3 (10-12cm) 2.5Y 4/2 (12-15cm)	+1.6
	10-15	2.5Y 4/4		2.5Y 4/2	+2
RCK7	0-2	2.5Y 4/4		2.5Y 4/2	+2
	2-5	2.5Y 4/4		2.5Y 4/2	+2
	5-10	2.5Y 4/4		2.5Y 4/2	+2
	10-15	2.5Y 4/4		2.5Y 4/2	+2

Table 33 continued

RCK8	0-2	10YR 4/3	2.5Y 3/3	5Y 4/2	+1
	2-5	10YR 4/3		5Y 4/2	+1
	5-10	10YR 4/3		5Y 4/2	+1
	10-15	10YR 4/3		5Y 4/2	+1
RCK9	0-2	10YR 2/1	2.5Y 4/2.5	7.5YR 5/8	**-6.25**
	2-5	2.5Y 4/4		7.5YR 5/8	**-4**
	5-10	2.5Y 4/4		7.5YR 5/8	**-4**
	10-15	2.5Y 4/4		7.5YR 5/8	**-4**
RCK10	0-2	7.5YR 2.5/1	2.5Y 4/4	2.5Y 5/4	**-1.5**
	2-5	2.5Y 4/4		2.5Y 5/4	**0**
	5-10	2.5Y 4/4		2.5Y 5/4	**0**
	10-15	2.5Y 4/4		2.5Y 5/4 (10-13cm) 5YR 4/6 (13-15cm)	**-0.8**
RCK11	0-2	2.5Y 4/4		10YR 5/6 and 5Y 4/2	0
	2-5	2.5Y 4/4		10YR 5/6 and 5Y 4/2	0
	5-10	2.5Y 4/4		10YR 5/6 and 5Y 4/2	0
	10-15	2.5Y 4/4		10YR 5/6 and 5Y 4/2	0
RCK12	0-2	2.5Y 3/3		2.5Y 3/3	0
	2-5	2.5Y 3/3		2.5Y 3/3	0
	5-10	2.5Y 3/3		2.5Y 3/3	0
	10-15	2.5Y 4/4		2.5Y 3/3	+1
RCK13	0-2	2.5Y 4/4	2.5Y 3/3	2.5Y 5/2	+1.5
	2-5	2.5Y 4/4		2.5Y 5/2	+2
	5-10	2.5Y 4/4		2.5Y 5/2	+2
	10-15	2.5Y 4/3.5		2.5Y 5/2	+1.5
RCK14	0-2	2.5Y 4/4	2.5Y 3/3	2.5Y 5/3	+0.5
	2-5	2.5Y 4/4		2.5Y 5/3	+1
	5-10	2.5Y 4/4		2.5Y 5/3	+1
	10-15	2.5Y 4/4		2.5Y 5/3	+1

5.6.7 SB Soil Chroma.

Table 34: SB Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
SB1	0-2	2.5Y 4/3		2.5Y 3/1 (redox feature)/D	roots and lots of OM
	2-5	2.5Y 4/3		5YR 5/8 (redox feature)/P	few roots, some OM
	5-10	2.5Y 4/2.5		10YR 4/6 (redox feature)/P	some roots, some OM; few shell fragments
	10-15	2.5 3.5/2		2.5Y 3/1 (redox feature)/F; 10YR 4/6 (redox feature)/P; 2.5YR 3/6 (redox feature)/P	very few fine roots, few shell fragments
SB3	0-2	2.5Y 4/3.5			some roots and OM; shell fragments
	2-5	2.5Y 4/3.5		7.5YR 5/8 (root channel)/P	some roots and OM; shell fragments
	5-10	2.5Y 4/3.5		7.5YR 5/8 (redox feature)/P	some OM; shell fragments
	10-15	2.5Y 4/3.5		7.5YR 5/8 (redox feature)/P; 5YR 4/6 (redox feature)/P	some OM; shell fragments
SB4	0-2	2.5Y 3/2			some roots, lots of OM
	2-5	2.5Y 3/2			some fine roots
	5-10	2.5Y 3/2		2.5Y 5/2 (redox feature)/F; 10YR 4/6 (redox feature)/P	some fine roots
	10-15	2.5Y 4/3	2.5Y 4/4; 2.5Y 3/2	10YR 5/6 (redox feature)/P	very few fine roots
SB5	0-2	2.5Y 3/2			some roots, lots of OM
	2-5	2.5Y 3/2			some roots, some OM
	5-10	2.5Y 3/2			
	10-15	2.5Y 3/2			
SB6	0-2	2.5Y 3/2			some roots, some OM
	2-5	2.5Y 4/2		2.5Y 7/2 (redox feature)/D 5YR 5/8 (root channel)/P	some fine roots
	5-10	2.5Y 4/2		5YR 3/4 (root channel)/P	some fine roots
	10-15	2.5Y 4/2		5YR 5/8 (root channel)/P	some roots and OM
SB7	0-2	2.5Y 4/3			some roots and OM
	2-5	2.5Y 4/3			some roots and OM
	5-10	2.5Y 4/3			some roots and OM
	10-15	2.5Y 4/3.5		2.5Y 5/1 (redox feature)/D 2.5Y 3/1 (redox feature)/D	some fine roots
SB8	0-2	2.5Y 3/1.5			some roots and OM
	2-5	2.5Y 3/2			some fine roots
	5-10	2.5Y 3/2			some roots, some OM
	10-15	2.5Y 3/2			some roots, some OM

Table 34 continued

SB9	0-2	2.5Y 4/2		5YR 5/8 (redox feature)/P	some roots, some OM
	2-5	2.5Y 3.5/2		5YR 5/8 (redox feature)/P	few fine roots
	5-10	2.5Y 3/2		2.5Y 4/4 (redox feature)/D 10YR 5/6 (redox feature)/P	some roots, some shell fragments
	10-15	2.5Y 3/2	2.5Y 4/2	7.5YR 5/8 (root channel)/P	some shell fragments
SB10	0-2	2.5Y 3/2			some roots, lots of OM
	2-5	2.5Y 3/2			some roots, some OM
	5-10	2.5Y 3/2			few roots, little OM
	10-15	2.5Y 3/1.5		5YR 3/4 (redox feature)/P	some roots, some OM

* See Table 20 for a description

Table 35: SB Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
SB1	0-2	2.5Y 4/3		2.5Y 4/3	**0**
	2-5	2.5Y 4/3		2.5Y 4/3	**0**
	5-10	2.5Y 4/2.5		2.5Y 4/3	**-0.5**
	10-15	2.5 3.5/2		2.5Y 4/3 (10-12cm) 2.5Y 4/1 (12-15cm)	**-0.2**
SB3	0-2	2.5Y 4/3.5		2.5Y 4/2	+1.5
	2-5	2.5Y 4/3.5		2.5Y 4/2	+1.5
	5-10	2.5Y 4/3.5		2.5Y 4/2	+1.5
	10-15	2.5Y 4/3.5		2.5Y 4/2	+1.5
SB4	0-2	2.5Y 3/2		10YR 4/1	+1
	2-5	2.5Y 3/2		10YR 4/1	+1
	5-10	2.5Y 3/2		10YR 4/1 (5-6 cm) 10YR 4/3 (6-10cm)	-0.6
	10-15	2.5Y 4/3	2.5Y 4/4; 2.5Y 3/2	10YR 4/3	0
SB5	0-2	2.5Y 3/2		2.5Y 3/1	+1
	2-5	2.5Y 3/2		2.5Y 3/1	+1
	5-10	2.5Y 3/2		2.5Y 3/1	+1
	10-15	2.5Y 3/2		2.5Y 3/1	+1
SB6	0-2	2.5Y 3/2		2.5Y 3/2	**0**
	2-5	2.5Y 4/2		2.5Y 3/2	**0**
	5-10	2.5Y 4/2		2.5Y 3/2 (10-11cm) 2.5Y 5/3 (11-15cm)	**-0.8**
	10-15	2.5Y 4/2		2.5Y 5/3	**-1**
SB7	0-2	2.5Y 4/3		2.5Y 4/3	0
	2-5	2.5Y 4/3		2.5Y 4/3	0
	5-10	2.5Y 4/3		2.5Y 4/3	0
	10-15	2.5Y 4/3.5		2.5Y 4/3	+0.5
SB8	0-2	2.5Y 3/1.5		10YR 3/1	+0.5
	2-5	2.5Y 3/2		10YR 3/1	+1
	5-10	2.5Y 3/2		10YR 3/1	+1
	10-15	2.5Y 3/2		10YR 3/1	+1

Table 35 continued

SB9	0-2	2.5Y 4/2	10YR 3/1	+1
	2-5	2.5Y 3.5/2	10YR 3/1	+1
	5-10	2.5Y 3/2	10YR 3/1	+1
	10-15	2.5Y 3/2	10YR 3/1	+1
SB10	0-2	2.5Y 3/2	10YR 3/1	+1
	2-5	2.5Y 3/2	10YR 3/1	+1
	5-10	2.5Y 3/2	10YR 3/1	+1
	10-15	2.5Y 3/1.5	10YR 3/1	+0.5

5.6.8 SCW Soil Chroma.

Table 36: SCW Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
SCW1		ND			
SCW2		ND			
SCW3		ND			
SCW4		ND			
SCW5		ND			
SCW6	0-2	2.5Y 4/3.5		2.5YR 3/4 (redox feature and root channels)/F	some fine roots, some OM
	2-5	2.5Y 4/3.5		10YR 5/6 (root channels)/P	some roots and OM
	5-10	2.5Y 4/3.5		2.5Y 6/4 (redox feature)/F; 10YR 5/6 (redox feature)/P	few roots
	10-15	2.5Y 4/4			

* See Table 20 for a description

Table 37: SCW Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
SCW1		ND			
SCW2		ND			
SCW3		ND			
SCW4		ND			
SCW5		ND			
SCW6	0-2	2.5Y 4/3.5		7.5YR 4/4	**-0.5**
	2-5	2.5Y 4/3.5		7.5YR 4/4	**-0.5**
	5-10	2.5Y 4/3.5		7.5YR 4/4	**-0.5**
	10-15	2.5Y 4/4		7.5YR 4/4	**0**

5.6.9 SWS Soil Chroma.

Table 38: SWS Soil Chroma. Abbreviations are according to the Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002), and the Munsell Soil Color Charts (Munsell 2000).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Redox Color (Depletion / Concretion) / Contrast*	Root and other Organic Matter Content
SWS1	0-2	2.5Y 2.5/1			lots of roots, lots of OM
	2-5	2.5Y 2.5/1	2.5Y 3/2	2.5Y 6/4 (redox feature)/D; 5YR 6/8 (redox feature)/P;	some roots and some OM
	5-10	2.5Y 2.5/1	2.5Y 3/2	5YR 5/8 (redox feature and root channels)/P; 2.5Y 7/2 (redox feature)/P	some roots, some OM
	10-15	2.5Y 2.5/1	2.5Y 3/2	5YR 5/8 (redox feature)/P; 2.5Y 7/3 (redox feature)/ D or P	some roots, some OM
SWS2	0-2	2.5Y 3/2	2.5Y 4.5/3		lots of roots
	2-5	10YR 2/1	2.5Y 4/2	2.5Y 7/2 (redox feature)/ P or D	lots of fine roots, some OM
	5-10	2.5Y 4/2	2.5Y 2.5/1	2.5Y 5/4 (redox feature)/D; 10YR 5/8 (root channel)/P	some larger roots
	10-15	2.5Y 4/3		2.5Y 6/4 (redox feature)/F; 2.5Y 7/6 (redox feature)/D; 7.5YR 2.5/1 (redox feature)/P	few roots
SWS3	0-2	10YR 4/1	10YR 2/1		lots of OM and roots
	2-5	2.5Y 2.5/1	10YR 4/1	10YR 5/8 (redox feature)/P; 2.5Y 7/4 (redox feature)/P	many roots
	5-10	2.5Y 2.5/1		10YR 7/3 (redox feature)/P; 10YR 6/8 (redox feature)/P	some fine roots
	10-15	2.5Y 2.5/1	2.5Y 4/2	10YR 5/8 (redox feature)/P	some OM
SWS4	0-2	2.5Y 2.5/1			lots of roots and OM
	2-5	2.5Y 2.5/1	2.5Y 4/1	2.5Y 6/6 (redox feature)/P	some roots
	5-10	2.5Y 2.5/1	2.5Y 4/1	2.5Y 6/6 (redox feature)/P	
	10-15	2.5Y 4/2	2.5Y 3/1	10YR 7/6 (clay streak)/P, 7.5YR 6/8 (redox feature)/P	
SWS5	0-2	2.5Y 2.5/1			some fine roots
	2-5	2.5Y 2.5/1	2.5Y 4/1	10YR 6/8 (redox feature)/P 2.5Y 6/3 (redox feature)/D	some roots, some OM
	5-10	2.5Y 2.5/1	2.5Y 4/1	2.5Y 6/6 (redox feature)/P; 5YR 5/8 (redox feature)/P	some larger roots
	10-15	2.5Y 2.5/1	2.5Y 5/3	2.5Y 6/6 (redox feature)/P; 5YR 5/8 (redox feature)/P	

Table 38 continued

SWS6	0-2	5Y 2.5/2		2.5Y 6/6 (redox feature)/P	lots of fine roots
	2-5	2.5Y 4/2		2.5Y 7/6 (redox feature)/P; 10R 5/8 (root channel)/P; 10R 4/6 (root channel)/P;	lots of fine roots
	5-10	5Y 2.5/1	2.5Y 3/2	2.5Y 6/4 (redox feature)/P or D; 5YR 5/8 (redox feature)/P; 10R 5/6 (root channel)/P	lots of fine roots
	10-15	5Y 2.5/1	2.5Y 5/3	10Y 8/1 (clay streak)/P; 2.5YR 5/8 (root channel)/P; 2.5Y 7/6 (redox feature)/P or D	lots of fine roots
SWS7	0-2	2.5Y 3/2			lots of fine roots and OM
	2-5	2.5Y 2.5/1	2.5Y 4/2	7.5YR 5/8 (redox feature)/P	some fine roots
	5-10	2.5Y 2.5/1	2.5Y 4/2	7.5YR 6/8 (root channels and redox feature)/P	lots of fine and some larger roots (1mm)
	10-15	2.5Y 2.5/1	2.5Y 4/3	5YR 5/8 (root channel and redox feature)/P	some larger roots
SWS8	0-2	2.5Y 3/1		2.5Y 5/4 (redox feature)/D	lots of fine roots and OM
	2-5	2.5Y 2.5/1	2.5Y 3/2	7.5YR 6/8 (redox feature and root channels)/P; 10YR 7/4 (redox feature)/P	lots of fine roots, some larger (1.5mm diameter)
	5-10	2.5Y 2.5/1	2.5Y 3/2	5 YR 5/6 (root channels)/P, 2.5 Y 5/4 (redox feature)/D	lots of fine roots
	10-15	2.5Y 2.5/1	2.5Y 4/3	2.5Y 7/6 (redox feature)/P or D	
SWS9	0-2	2.5Y 4/2		2.5 Y 5/4 (redox feature)/D	lots of fine roots and OM
	2-5	2.5Y 4/2	2.5Y 3/1	10yr 5/8 (root channel)/P	
	5-10	2.5Y 4/2		2.5Y 7/6 (redox feature)/P, 5 YR 5/8 (redox feature)/P	lots of fine roots
	10-15	2.5Y 2.5/1	2.5Y 4/2	10YR 5/6 (many redox feature)/P	some fine roots
SWS10	0-2	2.5Y 3/2		2.5 Y 5/6 (redox feature)/P	lots of fine roots
	2-5	2.5Y 4/2	2.5Y 3/1	5YR 5/8 (root channel)/P	
	5-10	2.5Y 2.5/1		2.5Y 6/6 (redox feature)/P 2.5YR 4/6 (root channel)/P; 10B 8/1 (redox feature)/P	lots of fine roots, some larger (1.5mm diameter)
	10-15	5Y 2.5/2		2.5Y 4/3 (redox feature)/P; 5YR 5/6 (redox feature)/P	few fine roots

* See Table 20 for a description

Table 39: SWS Soil Chroma. Abbreviations are according to the Munsell Soil Color Charts (Munsell 2000). Bolded (negative) chroma change indicates soil chroma reduction. Positive chroma change indicates soil oxidation since Fajardo (2006).

Plot	Depth (cm)	1° Matrix Color	2° Matrix Color	Fajardo (2006) Matrix Color	Chroma Change
SWS1	0-2	2.5Y 2.5/1		2.5Y 5/4	**-3**
	2-5	2.5Y 2.5/1	2.5Y 3/2	2.5Y 5/4	**-2.5**
	5-10	2.5Y 2.5/1	2.5Y 3/2	2.5Y 5/4	**-2.5**
	10-15	2.5Y 2.5/1	2.5Y 3/2	2.5Y 5/4	**-2.5**
SWS 2	0-2	2.5Y 3/2	2.5Y 4.5/3	N 2.5/0 and 10YR 5/2	+1.5
	2-5	10YR 2/1	2.5Y 4/2	N 2.5/0 and 10YR 5/2	+0.5
	5-10	2.5Y 4/2	2.5Y 2.5/1	N 2.5/0 and 10YR 5/2	+0.5
	10-15	2.5Y 4/3		2.5Y 4/1 and 2.5Y 5/3	+1
SWS 3	0-2	10YR 4/1	10YR 2/1	10YR 6/6 and 10YR 2/1	**-2.5**
	2-5	2.5Y 2.5/1	10YR 4/1	10YR 6/6 and 10YR 2/1	**-2.5**
	5-10	2.5Y 2.5/1		10YR 6/6 and 10YR 2/1	**-2.5**
	10-15	2.5Y 2.5/1	2.5Y 4/2	10YR 6/6 and 10YR 2/1	**-2**
SWS 4	0-2	2.5Y 2.5/1		N 2.5/0 and 2.5Y 5/3	**-0.5**
	2-5	2.5Y 2.5/1	2.5Y 4/1	N 2.5/0 and 2.5Y 5/3	**-0.5**
	5-10	2.5Y 2.5/1	2.5Y 4/1	N 2.5/0 and 2.5Y 5/3	**-0.5**
	10-15	2.5Y 4/2	2.5Y 3/1	N 2.5/0 and 2.5Y 5/3	**0**
SWS 5	0-2	2.5Y 2.5/1		N 2.5/0 and 2.5Y 5/3	**-0.5**
	2-5	2.5Y 2.5/1	2.5Y 4/1	N 2.5/0 and 2.5Y 5/3	**-0.5**
	5-10	2.5Y 2.5/1	2.5Y 4/1	N 2.5/0 and 2.5Y 5/3	**-0.5**
	10-15	2.5Y 2.5/1	2.5Y 5/3	N 2.5/0 and 2.5Y 5/3 (10-12cm) 10YR 5/6 (12-15cm)	**-2.2**

Table 39 continued

SWS 6	0-2	5Y 2.5/2		5Y 3/1	+1
	2-5	2.5Y 4/2		5Y 3/1	+1
	5-10	5Y 2.5/1	2.5Y 3/2	5Y 3/1	+0.5
	10-15	5Y 2.5/1	2.5Y 5/3	5Y 3/1	+1
SWS7	0-2	2.5Y 3/2		2.5Y 5/2	**0**
	2-5	2.5Y 2.5/1	2.5Y 4/2	2.5Y 5/2	**-0.5**
	5-10	2.5Y 2.5/1	2.5Y 4/2	2.5Y 5/2	**-0.5**
	10-15	2.5Y 2.5/1	2.5Y 4/3	2.5Y 5/2	**0**
SWS8	0-2	2.5Y 3/1		5Y 4/2 and 10YR 3/1	-0.5
	2-5	2.5Y 2.5/1	2.5Y 3/2	5Y 4/2 and 10YR 3/1	0
	5-10	2.5Y 2.5/1	2.5Y 3/2	5Y 4/2 and 10YR 3/1	0
	10-15	2.5Y 2.5/1	2.5Y 4/3	5Y 4/2 and 10YR 3/1	+0.5
SWS9	0-2	2.5Y 4/2		2.5Y 4/1	+1
	2-5	2.5Y 4/2	2.5Y 3/1	2.5Y 4/1	+0.5
	5-10	2.5Y 4/2		2.5Y 4/1	+1
	10-15	2.5Y 2.5/1	2.5Y 4/2	2.5Y 4/1	+0.5
SWS10	0-2	2.5Y 3/2		7.5YR 3/1	+1
	2-5	2.5Y 4/2	2.5Y 3/1	7.5YR 3/1	+1
	5-10	2.5Y 2.5/1		7.5YR 3/1	0
	10-15	5Y 2.5/2		7.5YR 3/1	+1

5.7: Relevant Statistics by Depth.

Table 40: Relevant Statistics by Depth. Depth comparisons with 0-2 cm depth for selected variables at each site using Wilcoxon Sign-Rank Test. *Differences are significant where $p \leq 0.05$. SCW could not be statistically analyzed due to an insufficient amount of samples.

Site	Depth	0 - 2 cm						
		MSPD	% OM	% C	% N	C:N	% Fe	% P
CCW	2-5cm	**0.005***	**0.005***	**0.005***	**0.005***	0.114	0.168	**0.005***
	5-10cm	**0.005***	**0.007***	**0.005***	**0.005***	**0.005***	0.184	**0.005***
	10-15cm	**0.005***	**0.005***	**0.005***	**0.005***	**0.005***	0.082	**0.005***
DC	2-5cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	0.051	**0.008***
	5-10cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	**0.007***	**0.008***
	10-15cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	**0.012***	**0.008***
MAN	2-5cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	0.678	**0.010***
	5-10cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	0.859	**0.008***
	10-15cm	**0.008***	**0.008***	**0.008***	**0.007***	**0.008***	0.314	**0.011***
MATTA	2-5cm	**0.005***	**0.005***	**0.005***	**0.005***	0.169	**0.008***	**0.008***
	5-10cm	**0.005***	**0.005***	**0.005***	**0.005***	0.093	0.126	**0.005***
	10-15cm	**0.005***	**0.005***	**0.005***	**0.005***	0.386	0.343	**0.005***
MTS	2-5cm	**0.005***	**0.017***	**0.007***	**0.007***	**0.047***	0.477	**0.009***
	5-10cm	**0.005***	**0.037***	**0.005***	**0.005***	**0.005***	0.528	**0.007***
	10-15cm	**0.005***	0.074	**0.005***	**0.005***	**0.005***	0.084	**0.011***
RCK	2-5cm	**0.001***	**0.001***	**0.001***	**0.001***	**0.011***	0.162	**0.002***
	5-10cm	**0.001***	**0.001***	**0.001***	**0.001***	**0.002***	0.485	**0.001***
	10-15cm	**0.001***	**0.001***	**0.001***	**0.001***	**0.001***	0.807	**0.002***
SB	2-5cm	**0.008***	**0.008***	**0.008***	**0.008***	**0.008***	0.326	**0.007***
	5-10cm	**0.008***	**0.008***	**0.008***	**0.007***	0.066	**0.025***	**0.011***
	10-15cm	**0.008***	**0.008***	**0.008***	**0.008***	0.110	**0.015***	**0.011***
SWS	2-5cm	**0.005***	**0.005***	**0.005***	**0.009***	0.074	0.358	**0.005***
	5-10cm	**0.005***	**0.005***	**0.007***	**0.007***	**0.017***	0.953	**0.005***
	10-15cm	**0.005***	**0.005***	**0.005***	**0.005***	**0.037***	0.293	**0.005***

Table 41: Relevant Statistics by Depth. Depth comparisons with 2-5cm depth for selected variables at each site using Wilcoxon Sign-Rank Test. *Differences are significant where $p \leq 0.05$. SCW could not be statistically analyzed due to an insufficient amount of samples.

Site	Depth	2-5 cm						
		MSPD	% OM	% C	% N	C:N	% Fe	% P
CCW	5-10 cm	**0.005***	0.074	**0.007***	**0.008***	**0.013***	0.414	**0.007***
	10-15 cm	**0.005***	**0.005***	**0.005***	**0.005***	**0.007***	0.236	**0.008***
DC	5-10 cm	**0.008***	0.051	**0.024***	0.932	0.066	0.212	0.605
	10-15 cm	**0.008***	0.086	0.110	0.952	0.110	0.624	0.660
MAN	5-10 cm	**0.008***	0.553	**0.012***	**0.020***	**0.012***	0.441	0.090
	10-15 cm	**0.008***	0.441	**0.008***	**0.018***	**0.021***	0.953	0.176
MATTA	5-10 cm	**0.017***	0.059	0.059	**0.018***	0.721	0.097	0.063
	10-15 cm	**0.005***	0.074	**0.036***	**0.007***	0.767	**0.050***	0.280
MTS	5-10 cm	**0.005***	0.594	**0.007***	0.057	**0.037***	0.767	0.106
	10-15 cm	**0.005***	0.721	**0.005***	**0.015***	**0.007***	0.261	0.165
RCK	5-10 cm	**0.002***	0.173	**0.007***	**0.001***	0.055	0.221	0.248
	10-15 cm	**0.001***	**0.009***	**0.001***	**0.003***	**0.002***	0.221	**0.032***
SB	5-10 cm	**0.008***	0.858	**0.012***	**0.007***	**0.008***	0.066	**0.031***
	10-15 cm	**0.015***	0.594	**0.008***	0.121	**0.011***	**0.038***	0.090
SWS	5-10 cm	**0.007***	0.114	0.093	0.307	0.285	0.553	0.074
	10-15 cm	**0.009***	**0.037***	**0.013***	0.074	0.241	**0.026***	**0.012***

Table 42: Relevant Statistics by Depth. Depth comparisons with 5-10 cm depth for selected variables at each site using Wilcoxon Sign-Rank Test. *Differences are significant where $p \leq 0.05$. SCW could not be statistically analyzed due to an insufficient amount of samples.

Site	Depth	5-10 cm						
		MSPD	% OM	% C	% N	C:N	% Fe	% P
CCW	10-15 cm	**0.028***	**0.007***	**0.017***	0.018	**0.028***	0.722	0.072
DC	10-15 cm	0.260	0.594	0.623	0.723	0.678	0.953	0.317
MAN	10-15 cm	0.173	0.767	0.173	0.091	0.859	0.260	0.726
MATTA	10-15 cm	0.241	0.374	0.507	0.730	0.284	0.944	0.943
MTS	10-15 cm	**0.005***	0.953	**0.032***	0.101	0.093	0.594	0.952
RCK	10-15 cm	**0.019***	**0.046***	**0.006***	0.072	**0.001***	0.529	0.202
SB	10-15 cm	0.594	0.314	0.192	**0.007***	**0.015***	0.172	0.187
SWS	10-15 cm	0.114	0.646	0.308	0.092	0.575	**0.041***	0.220

5.8: Relevant Statistics Among Sites. Overall site mean comparisons for selected variables at each site using Wilcoxon Rank Sum Test (Mann-Whitney U Test). *Differences are significant where p ≤0.05. SCW site data arises from a single plot rather than a site mean.

5.8.1 Modified Soil Particle Density (MSPD)

Table 43: Relevant Statistics Among Sites for Modified Soil Particle Density.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.343							
MAN	0.686	0.686						
MATTA	0.200	0.486	0.343					
MTS	0.343	0.486	0.486	0.886				
RCK	0.343	0.886	0.686	0.343	0.486			
SCW	0.570	0.114	0.114	0.686	0.886	0.200		
SB	0.114	0.200	0.114	0.343	0.343	0.200	0.686	
SWS	0.343	1.000	0.686	0.686	0.686	0.886	0.200	0.200

5.8.2 Organic Matter (OM)

Table 44: Relevant Statistics Among Sites for Percent Organic Matter.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.686							
MAN	0.886	0.200						
MATTA	0.486	0.686	0.200					
MTS	0.114	0.200	0.114	0.200				
RCK	1.000	0.200	0.343	0.200	0.200			
SCW	0.686	0.486	0.114	0.486	0.343	0.486		
SB	0.486	0.686	0.200	0.486	0.200	0.200	0.886	
SWS	0.886	0.200	0.486	0.200	0.200	0.886	0.886	0.343

5.8.3 Total Carbon

Table 45: Relevant Statistics Among Sites for Total Carbon.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.686							
MAN	0.886	0.886						
MATTA	0.886	0.200	0.486					
MTS	0.886	0.886	1.000	0.486				
RCK	1.000	0.686	0.886	0.686	0.886			
SCW	0.486	0.686	0.343	**0.029***	0.200	0.200		
SB	0.886	0.343	0.486	0.886	0.343	0.486	**0.029***	
SWS	0.486	0.200	0.343	0.200	0.200	0.200	**0.029***	0.343

5.8.4 Total Nitrogen

Table 46: Relevant Statistics Among Sites for Total Nitrogen.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.200							
MAN	0.886	0.343						
MATTA	0.686	0.343	0.686					
MTS	0.686	0.200	0.486	0.486				
RCK	0.886	0.343	0.886	0.486	0.343			
SCW	0.343	**0.029***	0.343	0.114	**0.029***	0.343		
SB	0.886	0.114	0.886	0.486	0.343	1.000	0.343	
SWS	0.200	0.486	0.486	0.486	0.114	0.200	**0.029***	0.057

5.8.5 C:N

Table 47: Relevant Statistics Among Sites for C:N.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.057							
MAN	0.486	**0.029***						
MATTA	0.486	**0.029***	0.200					
MTS	0.343	0.114	0.486	**0.029***				
RCK	0.886	**0.029***	0.343	0.343	0.057			
SCW	0.486	**0.029***	0.486	0.057	0.200	0.686		
SB	0.486	**0.029***	0.057	0.343	**0.029***	0.057	0.057	
SWS	0.486	**0.029***	0.886	**0.029***	0.200	0.486	0.486	**0.029***

5.8.6 Total Iron

Table 48: Relevant Statistics Among Sites for Total Iron.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	**0.029***							
MAN	**0.029***	**0.029***						
MATTA	**0.029***	**0.029***	**0.029***					
MTS	**0.029***	**0.029***	**0.029***	0.114				
RCK	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***			
SCW	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***		
SB	**0.029***	**0.029***	**0.029***	0.886	0.200	**0.029***	**0.029***	
SWS	0.200	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***

5.8.7 Total Phosphorus

Table 49: Relevant Statistics Among Sites for Total Phosphorus.

Site	CCW	DC	MAN	MATTA	MTS	RCK	SCW	SB
DC	0.343							
MAN	0.114	**0.029***						
MATTA	0.114	0.114	0.686					
MTS	0.200	0.200	0.200	0.200				
RCK	0.200	0.200	0.200	0.200	0.486			
SCW	0.343	0.343	**0.029***	0.057	0.886	0.343		
SB	0.686	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***	**0.029***	
SWS	0.886	0.200	**0.029***	0.114	0.200	0.200	0.343	0.343

VITA

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